MINISTRY OF HEALTH

COMMITTEE ON MEDICAL AND NUTRITIONAL ASPECTS OF FOOD POLICY

# REPORT OF THE WORKING PARTY ON IRRADIATION OF FOOD



*LONDON*
HER MAJESTY'S STATIONERY OFFICE
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# COMMITTEE ON MEDICAL AND NUTRITIONAL ASPECTS OF FOOD POLICY

The terms of reference of the Committee on Medical and Nutritional Aspects of Food Policy are:—

To consider and advise on:—

(a) the medical and scientific aspects of policy in relation to nutrition;

(b) at the request of or in association with the Food Standards Committee, the Food Additives and Contaminants Committee, the Advisory Committee on Pesticides and other Toxic Chemicals, or any other committee as appropriate, the medical and nutritional aspects of risks to human health associated with the introduction of new substances and practices in the agricultural and food industries; and

(c) at the request of Departments, any matters falling within these terms of reference.

The members of the Committee on Medical and Nutritional Aspects of Food Policy are:

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# REPORT OF THE WORKING PARTY ON IRRADIATION OF FOOD

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# COMMITTEE ON MEDICAL AND NUTRITIONAL ASPECTS OF FOOD POLICY REPORT ON IRRADIATION OF FOOD

The Committee on Medical and Nutritional Aspects of Food Policy have considered and accepted the Report of their Working Party on the Irradiation of Food and fully endorse the recommendations of the Working Party. The Committee wish to express their thanks to the Chairman and Members of the Working Party for the very considerable amount of work involved in the preparation of the report.

The Report of the Working Party on the Irradiation of Food, received in March, 1964, is as follows:

## INTRODUCTION

### Appointment and Terms of Reference of the Working Party

1. The Working Party was appointed early in 1962 by the Chief Medical Officer of the Ministry of Health on the advice of the Committee on Medical and Nutritional Aspects of Food Policy. The terms of reference were:

> "To review the medical and scientific information available about the effect of irradiation upon food, including any changes in its nutritive value, and the possible hazards to man that might thereby arise, and to report to the Committee whether this indicates a need for control, and possibly, the principles which should govern any official control."

### Membership

2. The Membership of the Working Party was as follows:—

Professor F. G. Young, Head of the Department of Biochemistry, University of Cambridge, (*Chairman*).

Dr. H. R. Barnell, Chief Scientific Adviser (Food), Ministry of Agriculture, Fisheries and Food.

Dr. J. M. Barnes, Director of the Toxicology Unit, Medical Research Council Laboratories, Carshalton, Surrey.

Professor E. Boyland, Professor of Biochemistry, University of London at the Chester Beatty Research Institute: Institute of Cancer Research: Royal Cancer Hospital.

Professor A. C. Frazer, Head of the Department of Medical Biochemistry and Pharmacology, University of Birmingham.

The Joint Secretaries of the Working Party were Dr. W. T. C. Berry and Mrs. M. A. J. Pearson, assisted by Mr. S. J. Wright, all of the Ministry of Health.

3. Throughout its discussions the Working Party has been assisted by Mr. F. J. Ley, of the Isotope Research Division, Wantage Research Laboratory (Atomic Energy Research Establishment), and by Dr. J. M. Ross, Ministry of Health. From time to time other officers of the Ministry of Health have assisted the Working Party, and also officers of the Ministry of Agriculture, Fisheries and Food. A list of those who have greatly helped the Working Party by giving evidence before it, by making available unpublished information, by reading and commenting on parts of the Report in draft form, and in other ways, is given at the end of the Report.

## Meetings

4. The Working Party has met on sixteen occasions, and has reviewed all available published and unpublished material on the effect of radiation upon food of which it was aware.

## Form of the Report

5. This Report is intended to be understandable by the medical man or scientist who has no special knowledge of nuclear physics or of microbiology. To those who have special knowledge of such subjects parts of the Report may appear to be superfluous but in the opinion of the Working Party these sections may nevertheless be helpful to some readers. A Glossary is attached to the Report (pages 38-45) which defines some of the terms used in the physical sections. Historical and other relevant background information about microbiology is given in Appendix IV while similar material concerning nuclear physics appears in Appendices I and II.

6. The main body of the Report (paragraphs 1-149) should be understandable without study of the Appendices. As far as possible special technical material has been given in the Appendices only. The authorship is indicated of those Appendices which were prepared separately from the main Report. Two of these Appendices (Appendices II and III) were prepared by experts who were consulted by the Working Party but who were not members of it.

7. References to the publications consulted and to other sources of information are kept to a minimum in the main body of the Report. A list of the principal sources of information appears at the end of the Report.

## Legislative Background and Possible Forms of Control

8. Under the Food and Drugs Act, 1955, and the corresponding Scottish Act of 1956, it is an offence to subject food, intended to be sold for human consumption, to any process or treatment that renders the food injurious to health. The probable cumulative effect of consuming the food in ordinary quantities is taken into account in considering whether or not the food is injurious to health. It can also be an offence to sell for human consumption food which is not of the nature, substance or quality demanded, or food which is unfit for human consumption unless notice is given to the purchaser that the food is not intended for human consumption. In every case brought under these Acts the onus is on the prosecution to prove to the satisfaction of the Court the allegation as to the harmfulness, unsatisfactory quality or unfitness for human consumption, of the food in question. Whether or not the sale of irradiated food contravenes the provisions of the Acts is therefore a matter for the Court to decide when a prosecution is brought before it. At the present time no food which has been irradiated to prolong its storage life is known to have been offered for sale for human consumption in Great Britain, and no proceedings have been taken in respect of such a sale under the English or Scottish Acts.

9. In a number of countries the Government either already has the power to control the sale of irradiated food or is considering legislation appropriate to achieve this.

10. In the United Kingdom the present tendency with respect to the formulation of regulations under the Food and Drugs Acts is towards positive control of its composition and treatment, rather than by the negative method of awaiting a

decision of the Court that in a specific instance an offence had been committed under one of the general provisions in the Food and Drugs Acts. This tendency is well illustrated by some recent regulations made under these Acts whereby the addition to food of preservatives and certain other substances is prohibited except for those which appear on a list of permitted additives. Other regulations under these Acts lay down requirements as to the composition of certain foods.

11. It is not for the Working Party to advise on the precise form, legislative or otherwise, of any official control of the use of radiation for the treatment of food which may be needed. It was, however, asked to consider the principles which should govern such control as it might deem to be necessary and it concludes that there are in principle three possible lines of approach which are set out in paragraphs 12, 13 and 14.

12. In the absence of evidence to the contrary treatment by radiation might be regarded as liable to contribute a hazard to health no more, and no less, than do methods of preservation by, for example, refrigeration or heat-treatment already widely in use. If this view were accepted the provisions referred to in paragraph 8 would be a sufficient safeguard and, subject to these, industry would bear the responsibility for ensuring that the treatment was satisfactory, in the absence of special control.

13. Every irradiated foodstuff and food product, and the kind and amount of irradia ion proposed for its treatment, might be regarded as providing a specific problem as a possible hazard to health. The acceptance of this point of view would indicate the need for prohibition of the sale for human consumption of all irradiated foodstuffs and food products unless specific exemption had first been secured. Exemption would be granted only for specified foodstuffs and food products which had been treated by radiation under closely defined conditions. Every application for exemption would have to be accompanied by evidence concerning the possible hazards to health involved, and the application and the accompanying evidence would be scrutinised by a group of experts. Exemption would be granted only if the group of experts was satisfied by the evidence set before it.

14. There is a course between the two extremes set out in paragraphs 12 and 13. A general prohibition would be introduced but exemption would be permitted for groups of foodstuffs and food products, as well as for individual items, and for ranges of treatment of given foods. If this course were adopted a possible danger might arise from the difficulty of defining in appropriate terms classes of foods for which exemption might be granted. Such a difficulty might be avoided if an application for exemption was required in respect of each food and its treatment, without evidence about the testing of the individual foodstuff for possible hazards to health necessarily being required if similar irradiated foodstuffs or food products had previously been granted exemption.

15. The Working Party reviewed the available evidence concerning the influence of radiation on food, and the hazards to health that could possibly arise from the consumption of irradiated food, with this legislative background and these possible forms of control in mind.

## FUNDAMENTAL CONSIDERATIONS

### Radiation

#### Definition of irradiation

16. The Working Party has interpreted its terms of reference in the sense that "irradiation" refers to treatment with ionising radiation. The results of treat-

ment of food by infra-red or ultra-violet radiation had therefore been considered only where the observations were germane to the main concern of the Working Party. "Ionising radiation" covers electromagnetic radiation of short wavelength (X-radiation from machines and gamma-radiation arising from the nuclear disintegration of radioactive substances), fast charged particles such as electrons, protons and alpha particles, and uncharged particles such as neutrons. Since proposals for the treatment of food by radiation are almost certain to be confined to the use of gamma-radiation and X-radiation and of fast electrons, the Working Party has confined its attention to the influence on food of these three types of ionising radiation. Where subsequently in this Report "radiation" or "ionising radiation" are written without qualification these terms refer only to these three types of ionising radiation.

**Sources of Ionising Radiation**

17. X-radiation is usually obtained from a machine designed for its production, and is distinguishable from gamma-radiation in that it consists of electromagnetic radiation of a wide variety of wavelengths. At the present time the use of X-radiation for the treatment of food on an industrial scale is not proposed, but the principles involved in its use for this purpose are the same as those in the employment of gamma-radiation. Where the use of gamma-radiation for the treatment of food is considered in this Report, the application of X-radiation is not specifically discussed but can be regarded as not differing in principle from that of gamma-radiation.

18. Gamma-radiation consists of electromagnetic radiation of sharply defined wavelengths, usually one or two in number, produced by the nuclear disintegration of certain radioactive substances. In industry the main, probably sole, source of gamma-radiation is likely to be an artificially-produced radioactive isotope of an otherwise non-radioactive substance (see Appendix I), a so-called "isotope source".

19. High speed electrons are obtained industrially from a machine which accelerates electrons emanating from a heated cathode (see Appendix I)—the so-called "machine sources". Fast electrons have much less penetrating power than X-radiation or gamma-radiation of the same energy but, in other respects, under the conditions of irradiation considered in this Report, treatment of food with fast electrons can be regarded as equivalent to treatment with a similar dose of X-radiation or gamma-radiation except with respect to the possible induction of radioactivity (see paragraph 27).

**Characterisation of Radiation**

20. The penetrating power is greater the higher the energy of the ionising radiation, but that of gamma-radiation and X-radiation is always greater than that of high speed electrons of the same energy. The extent of the chemical and physical changes induced in matter by ionising radiation depends on the amount of energy absorbed by the matter, and the nature of the atoms in the matter irradiated. It is also influenced by environmental conditions such as oxygen tension, temperature and pressure. The energy of X-radiation, gamma-radiation and fast electrons is usually expressed in terms of electron volts, the electron volt (or eV) being the energy ($1{\cdot}602 \times 10^{-12}$ erg) acquired by an electron when it is accelerated under the influence of a potential difference of one volt. Investigations concerning the possible industrial use of ionising radiation for

the treatment of food have been largely directed to the effects of radiation with energy of five million electron volts (5 MeV) or less, though some investigations have involved the use of radiation of energy up to 10 MeV or even more.

### Measurement of irradiation

21. A number of units have been devised for the measurement of ionising radiation, or of its effects.

### Rad

22. The rad is a unit based on the energy absorbed (which is not necessarily the same as that applied) from radiation by unit mass of irradiated material. The unit (rad) is 100 erg of energy released from the applied radiation in one gramme of irradiated matter.

### Röntgen

23. The röntgen was the original unit and defines the amount of radiation applied. Its use is limited to X-radiation and gamma-radiation up to 3 MeV. Measurements in terms of the röntgen are approximately the same as the rad as far as the irradiation of food is concerned. The exposure of biological material (tissue or food) to approximately 1·07 röntgen of X-radiation or gamma-radiation can result in the absorption of one rad (100 erg per gramme).

24. In this Report the energy absorbed from the applied radiation by the treated food is expressed in terms of "Megarad" (Mrad). One Megarad is 1,000,000 rad.

25. There is evidence that in certain non-biological systems the higher the rate of application of a given total amount of ionising radiation the less the total amount of chemical change induced. If this were true for the irradiation of food under the conditions considered in this Report the Megarad would not provide a valid basis for the comparision of the effects on food of different total doses of radiation unless the rate of application of the radiation were the same in every instance. An effect of this sort has been claimed with food irradiated with a very high rate of application of fast electrons [23] but this report lacks confirmation. For the conditions of irradiation of food under consideration in this Report the Working Party found no evidence that the chemical effects of a given absorbed dose of radiation alter with variations in its rate of application. Moreover, although some physical effects (e.g. on the atomic nucleus) of a given dose of radiation differ with the energy of the incident radiation (see paragraphs 26 to 28 and 82 to 94 below), no evidence was found that the chemical effects of a given dose differ with alterations in the energy of the radiation over the range of energies likely to be considered for the treatment of food. Accordingly, under the conditions of irradiation of food considered in this Report, the Megarad is acceptable as the basis of comparison of the chemical effects on food of different doses of radiation applied to the food at different rates.

### Mode of interaction of radiation with matter

26. When ionising radiation is absorbed by matter the energy of the radiation is usually ultimately dissipated as heat, though much of the energy appears in other forms before it is finally degraded to heat, and chemical changes may be

induced as a result. The amount of heat liberated by the dissipation of the energy provided by 1 Mrad of ionising radiation is 2·4 calories per gramme of irradiated matter, which would be enough to raise the temperature of one gramme of water by 2·4°C.

27. When ionising radiation impinges on matter energy may be imparted to the nuclei of the atoms of the matter, which are then said to have become "excited" by the absorption of radiation energy. Under some conditions, which include the use of radiation with high energy, the excitation may be sufficient to induce the atomic nucleus to become so unstable that it emits a neutron (or occasionally a charged particle) together with gamma-radiation, and this changes the atomic nucleus into that of a different substance, or that of an isotope of the original one. A neutron emitted in this way from an atomic nucleus may enter the nucleus of another atom and remain there. An atomic nucleus which loses or gains a nuclear particle may become radioactive, and the radioactive substance thus newly formed will begin a process of disintegration at a characteristic rate which may be measurable in terms of seconds or of centuries. In this way ionising radiation may induce the appearance of significant radioactivity in matter which previously possessed virtually none. Such radioactivity usually results in the emission of radiation different from that which excited the atomic nucleus in the first instance. Whether or not the appearance of radioactivity can be induced in this way depends on the nature of the matter irradiated and on the energy of the exciting radiation. For reasons which are discussed in Appendix I, and which are quantitatively illustrated in Appendix II, high speed electrons of a given energy are less effective in inducing radioactivity than X-radiation or gamma-radiation of the same energy. It may be noted here that with the gamma-radiation from the isotope sources which are under consideration for the treatment of food (Appendix I) no induction of radioactivity of this particular sort is possible in any atomic nucleus [275].

28. Under some conditions an atomic nucleus which has been excited by ionising radiation may not emit a particle but may remain in an excited state. This process of excitation of the atomic nucleus is sometimes referred to as "isomer activation", and the excited nucleus is described as being in a "metastable state". An atomic nucleus in such a metastable state is radioactive in that it releases gamma-radiation, of energy lower than that of the exciting radiation, at a rate which is characteristic of the atom and which may be measurable in terms of seconds or of months. The induction of isomer activation depends upon the nature of the matter irradiated and on the energy of the exciting radiation, high speed electrons of a given energy being less effective in this respect than X-radiation or gamma-radiation of the same energy. In general, isomer activation can be induced with radiation of energy less that than needed to induce the emission of a particle from the nucleus where this is able to take place. It may be noted that isomer activation does not occur in any circumstances with the atoms which make up the common constituents of food.

29. When ionising radiation of the energy likely to be used for the treatment of food passes into matter the chief effects are not produced by interaction between the radiation and the atomic nucleus but by the ejection of orbital electrons from those atoms which are excited by the radiation. Such electrons are conveniently referred to as primary electrons, and their ejection leaves behind a positively charged ion. The primary electrons may themselves interact with other atoms and ionise them, with the formation of more positive ions and a corresponding number of secondary ejected electrons. The latter possesses less

energy than the primary electrons which provoked their ejection. Some of the less energetic electrons may enter the electron shells of other atoms and, coming within the influence of the positive field of the atomic nucleus, may remain to form a negatively charged ion. The ultimate outcome of this process is the formation of equal numbers of positive and negative ions, and in water each secondary electron induces, on the average, the formation of about four pairs of ions, each pair consisting of a positive ion and a negative ion. Even if the interaction of an electron and an atom does not cause ionisation it may result in a transfer of some of the energy of the electron to the orbital electrons of the atom and in this way the extra-nuclear structure of the atom becomes excited. Excited neutral atoms may also result when a positive ion captures an electron and thus neutralises its own positive charge. Ultimately all the positive and negative charges mutually neutralise but before this occurs the atoms, and the molecules in which they may be contained, are likely to pass through many chemically reactive states.

30. If the atoms which become excited under the influence of the radiation are constituents of molecules, then the molecule as a whole may become excited, and the excitation may be great enough to cause the rupture of one or more chemical bonds in the molecule. The fracture of the molecule which is thus induced can give rise to free radicals, which may be electrically neutral but which nevertheless are highly chemically reactive and capable of starting chemical chain reactions.

31. In biological materials such as food, the direct action of radiation is mainly on the molecules of water and the influence of the radiation on the organic substances present is largely a secondary one. The interaction of the radiation with the molecules of water leads, by the sort of processes outlined above, to the formation of H and OH free radicals. These free radicals are highly chemically reactive and in particular are powerful reducing and oxidising agents. Their interaction with the organic molecules in the system results in chemical changes which may be quite different from those initiated, for example, by a rise of temperature.

32. Ehrenberg [87, 88] has suggested that some part of the energy released from the radiation impinging on irradiated food may be stored temporarily in a form of uncertain nature, and that this stored energy can later be released to bring about biologically important changes. No mechanism is recognised whereby radiation energy can be stored in food in a form from which it could be subsequently released to induce ionisation, other than that discussed in paragraph 28, although attempts have been made to substantiate the idea of such stored energy by hypothetical considerations[87]. The Working Party conclude, from a consideration of the relevant publications, that the suggestion that radiation energy in some undefined form may be stored in irradiated food provides no reason to suppose that a hazard could arise from such a cause as a result of the consumption of food treated by ionising radiation under the conditions considered in this Report.

## THE DEVELOPMENT OF THE USE OF IONISING RADIATION FOR THE TREATMENT OF FOOD

33. Evaluation of the advantages of the use of ionising radiations for the treatment of food is not within the terms of reference of the Working Party. It was not asked whether the irradiation of food would be advantageous, but

whether it should be controlled. It is thus for others to put the merits of the process in perspective, but effective consideration of the question of control necessitates a knowledge of the properties of ionising radiations which make their use attractive for the industrial treatment of food. These are set out in paragraphs 34, 35 and 36.

34. Among other uses ionising radiation in suitable doses can inhibit the breaking of dormancy of vegetables and can kill contaminating micro-organisms, parasites and infesting insects which may be present in food, without causing much rise of the temperature of the food. Raw food remains in the raw, uncooked state when it has been sterilised by irradiation, and frozen food can be sterilised while remaining frozen throughout the treatment.

35. Because ionising radiation possesses penetrating power food can be treated by it while packed and sealed in containers of such diverse materials as plastic, glass or metal. Subsequent contamination of packed and irradiated food is therefore most unlikely before the package is opened by the consumer.

36. Irradiation can be applied to food by a process that operates without interruption; unlike products treated with heat those sterilised by irradiation do not have to undergo heating and cooling or any other discontinuous process.

37. Although the use of radiation for the treatment of food has long been recognised, it is only recently that its employment on a large scale has been proposed and, in some instances, tried in practice in other countries.

38. The use of X-radiation for the treatment of food with a view to prolonging its useful storage life was patented in 1930 [349]. Interest in such application of ionising radiations was stimulated in 1947 by a publication [23] which described the potential industrial use of electron-beam generators for the sterilisation of food. The possible industrial usefulness of irradiation in this respect was reported upon in the United States of America in 1948. In that country research and development concerning the value of irradiated food is largely under the auspices of the Armed Forces. The U.S. Quartermaster General, in co-operation with the Surgeon General, has undertaken an extensive programme of research into the value of irradiation as a means of prolonging the period during which food can usefully be stored. The United States Atomic Energy Commission has a programme of research dealing mainly with the preservation of fish, fruit and vegetables by the application of relatively low doses of radiation.

39. In the United Kingdom investigation of the effects of radiation on food began in 1950 at the Low Temperature Research Station (of the Department of Scientific and Industrial Research and later of the Agricultural Research Council) at Cambridge, and research is now also carried out at the Wantage Research Laboratories of the Atomic Energy Research Establishment. Research on the effects of irradiating fish is pursued in conjunction with the Torry Research Station (Department of Scientific and Industrial Research) near Aberdeen. Other Government research institutes, as well as industrial research organisations and individual commercial firms, have also been interested in particular aspects of the application of radiation to food.

40. Research on this topic is also being carried out in many other countries. The published information is extensive, though some of the information made available to the Working Party remains unpublished.

41. In the United Kingdom, as in some other countries, isotope sources of gamma-radiation are now available in quantities which are sufficient to permit

the large-scale industrial use of radiation for the treatment of food. Machine sources of high speed electrons have also been developed and are available for commercial use.

42. In the United Kingdom experience has been gained in the industrial use of ionising radiation by the operation of plant designed to sterilise medical equipment, such as plastic syringes, largely by means of gamma-radiation from cobalt-60. The use of high speed electrons is also planned. In Australia ionising radiation has been employed on an industrial scale for some years for the elimination of anthrax bacilli from the baled goat hair which is used in the manufacture of carpets. The industrial use of radiation is being developed in many other countries also. Ionising radiation is already applied to food in commercial practice, or is under consideration by industry, for inspection and measurement. These applications are not centrally notified nor subject to specific control under the Food and Drugs Acts. The doses of irradiation applied are very low compared with those used for prolonging the storage life of food; even if the food was sequentially irradiated two or three times it is unlikely that the total dose would often exceed a few rads, and doses in excess of 1000 rads would be extremely unlikely. The Working Party would not expect any chemical change in the food or drink subjected to the low doses of irradiation involved and it is considered that the question of hazard from the proper use of such a low dose of irradiation can be dismissed. But consideration might well be given to a review of the extent to which such processes are used and to whether such processes should be notified or subject to some form of registration or licensing to rule out the possibility of hazard to the consumer.

## THE APPLICATION OF RADIATION TO THE TREATMENT OF FOOD

43. Although irradiation is already known to be effective as a means of prolonging the useful storage life of food, and the resources for its application on an industrial scale are available and are not unduly expensive, comparatively little use of it for this purpose has so far been made. One reason for this is that irradiation is liable to cause the development of unpleasant taste and odour in food. With many foods a dose of about 5 Mrad is needed to ensure sterility, and treatment with a dose of this magnitude can lead to such changes in odour and taste, and sometimes also in colour, that the food is liable to become unacceptable for human consumption. A possible exception to this general rule is bacon; a suitably prepared canned product is being sterilised by radiation in the United State for the Armed Forces. On the other hand when a low dose of radiation is used, for example 0·5 to 1·0 Mrad, little or no change in the quality of many foods is detectable.

44. The subsequent sections of this Report will be mainly concerned with the effects of irradiating food with 6 Mrad or less of radiation obtained either by means of machine sources which yield electrons of energy of 5 MeV or less, or by means of gamma-radiation from cobalt-60. The energy of the radiation from this isotope does not exceed 1·33 MeV. Investigations with food that has been irradiated under such conditions have provided most of the evidence so far available about the effects of radiation on it.

45. Some possible applications of ionising radiation to the treatment of food which have already been the subject of investigation are listed in Table 1. It is likely that other uses of irradiation will be discovered as the result of the extensive investigations now being carried out. The mechanism of action of the

radiation is unknown in many instances, but in the destruction of micro-organisms and the inhibition of sprouting of root crops, a possible common action is interference with the mechanism for cellular duplication which depends upon the integrity of the characteristic deoxyribonucleic acid of the cell (see paragraph 96 below).

TABLE 1

*Some possible applications of ionising radiation to the treatment of food*

| *Purpose* | *Required action of the irradiation* | *Dose of irradiation needed (Mrad)* |
|---|---|---|
| Sterilisation of meat for subsequent storage at room temperature | Destruction of all micro-organisms and parasites including spores of *Cl. botulinum* if present | 4–6 |
| Sterilisation of special ingredients of food, e.g. spices, celery seed | Destruction of bacteria liable to be present | 1–3 |
| An adjuvant to the use of heat for sterilisation of food | Sensitisation of bacterial spores to destruction by heat | 0·5 – 1·0 |
| Prevention of risk of salmonellae food-poisoning from e.g. frozen egg, coconut, meat | Destruction of *Salmonellae* | 0·5 – 1·0 |
| Extended cold storage (0°C – 4°C) of carcase meat and pre-packaged fish | Substantial reduction in numbers of spoilage bacteria, mostly in vegetative form | 0·3 – 0·5 |
| Prolongation of storage life of fruit | Destruction of moulds | 0·1 – 0·5 |
| Disinfestation of stored grain | Destruction of insects | 0·02 |
| Elimination of any parasites in meats | Destruction of *Trichinella spiralis, Cysticercus bovis* | 0·01 |
| Prolongation of storage life of root crops e.g. potatoes, onions | Inhibiting of sprouting | 0·01 |
| Hastening of ageing changes in alcoholic beverages | Chemical | 1 – 2 |
| Shortening of time needed for rehydration of dehydrated vegetables | Chemical or Physical | 0·25 – 2·5 |
| Enhancement of odour of essential oils | Chemical | 1 |

## THE CHANGES IN FOOD BROUGHT ABOUT BY TREATMENT WITH RADIATION

46. Food is a term which embraces many different types of material. In the United Kingdom many foods are cooked before consumption. Dairy products, many fruits and some vegetables are liable to be exceptions to this practice. Since irradiation is not a substitute for cooking the changes induced by irradia-

tion may be modified or supplemented by those brought about by cooking before the food is consumed. Any consideration of the effects of irradiation of food on human health clearly must take account of this somewhat complex situation.

47. The effect of radiation on a material separated from a complex food is often different and greater than that seen when the food itself is irradiated. In the food the presence of other molecules may protect a substance from the effect of the radiation. On the other hand peroxides produced by irradiation of fat may cause chemical changes in other components of the food. The results of investigations into the separated constituents of food must be interpreted with these considerations in mind.

48. A particular advantage of irradiation is that it can be used to treat food already packed, and packed in materials which can be less substantial than those used in the canning industry. The materials in which the food is packed for irradiation (and almost certainly for subsequent storage) are therefore themselves irradiated. Since highly reactive chemical free radicals are likely to be formed in any irradiated matter the Working Party has considered the possibility of interaction of the package and the food it contains, during and after irradiation, of a sort that would not occur in the absence of irradiation. The nature of the changes induced in food by irradiation ought therefore to be considered in relation to the conditions of packaging, and in the available accounts of investigations these are not always specified. There is, however, no reason to believe that under the conditions of irradiation considered in this Report radiation-induced interaction of food and package is likely to be of importance.

49. Some raw foodstuffs, such as the tissues of animals and of many plants, contain autolytic enzymes which can cause the disintegration of the tissue under sterile conditions. Irradiation with 5 Mrad or less, unlike cooking, does not destroy such autolytic enzymes so that unless other means are found to destroy the enzymes certain foods sterilised by irradiation would need to be stored at a cool temperature if disintegration of the tissue is to be prevented. This consideration applies especially to meat.

50. Because food is usually irradiated in containers, many of which are liable to be almost impermeable to air, irradiation and subsequent storage may take place under conditions which are anaerobic, or almost so. Since the changes which result from irradiation may depend to some extent on the presence or absence of oxygen, this question must be kept in mind when the relevance to industrial operations of experiments carried out under laboratory conditions is under consideration.

**Irradiation-induced chemical changes in food**

51. Though sterilising and some pasteurising doses of radiation (see paragraphs 43 and 103) may induce changes in food which are sufficient to affect taste and odour, the observed chemical alterations in the main constituents are small. The changes usually affect most of the constituents of the food, but they are not so great as to reduce significantly the digestibility and calorific value of the food as a whole [251, 147, 204, 268] when the food is irradiated under the conditions considered in this Report.

(a) *Influence on protein*

52. When purified proteins are irradiated alterations in their physical properties usually occur [251, 184, 29, 163]. Changes in the viscosity in solution and in

the rate of sedimentation in the ultracentrifuge have been observed which are suggestive both of splitting of the molecules, and of the formation of linkages between otherwise unaltered molecules or their split products. Such alterations could result from the fission, and reformation in a different way, of only a few chemical bonds, perhaps only one, in each protein molecule, and need involve no change in the constituent amino acids. Such changes would be expected to alter the immunochemical properties of the proteins and a reduction of the antigenic activity of proteins has indeed been observed.

53. Both an increase and a diminution in the sulphydryl groups of proteins have been described as following irradiation [163, 184, 276]. Proteins which possess sulphydryl groups usually contain the amino acid cysteine in peptide linkage and changes in the number of sulphydryl groups in each molecule of protein could easily be brought about by oxidation or reduction of the cysteine present. Under the influence of radiation both oxidising and reducing free radicals appear (paragraph 31).

54. Amino acids in combined form in proteins are less sensitive to the degrading actions of radiation than they are in the free state. The breakdown products derived from the amino acids combined in protein have not been clearly characterised, although sulphur-containing substances, and derivatives containing reactive carbonyl groups, are thought to arise from protein when meat is irradiated.

55. Tsien and Johnson [321] reported that when frozen ground beef at —20°C. is irradiated with 5·6 Mrad much of its glutamic acid and serine is destroyed, and significant changes occur in the amounts present of other amino acids. On the other hand Rhodes [265] observed that when frozen ground beef at 0°C. was irradiated with 5 Mrad the maximum destruction of any amino acid was 10 per cent, the sulphur containing amino acids being most affected. Rhodes has pointed out [265] that the maximal changes to be expected on theoretical grounds are of this order if certain reasonable assumptions are made. The reasons for the substantial differences between the results of Tsien and Johnson and of Rhodes are not clear. Recent American work [43] on a number of animal products irradiated showed no detectable destruction of amino acids.

56. Although a slight loss in the biological value of the protein of milk, accompanied by a rise in the sulphydryl content, has been reported by many workers [163, 184, 159] to follow gamma-radiation, most of the few investigations concerning the biological value of proteins in irradiated food have suggested that this is virtually unaltered [147, 204, 42, 96].

(*b*) *Influence on carbohydrates*

57. Most studies on the influence of irradiation on purified carbohydrates have been carried out with dilute solutions of carbohydrates treated with large doses, up to 100 Mrad, of radiation. Under such conditions monosaccharides are partly oxidised to the corresponding uronic acids, while polysaccharides are degraded, reducing substances and acidic substances being formed. Such changes would not be expected under the conditions of irradiation proposed for food. When foodstuffs have been irradiated under such conditions the main effect on the carbohydrate present has usually been a very slight increase in the amount of free sugar.

(*c*) *Influence on fat*

58. The irradiation of fats induces changes which are similar to those which result from autoxidation. The decomposition of the peroxides initially formed

under the influence of radiation usually results in the appearance of substances with reactive carbonyl groups, such as aldehydes and ketones [214]. As might be expected the irradiation of purified fats results in greater changes than are seen in the fat contained in food irradiated under similar conditions. It has been reported that animal fats are more susceptible to change on irradiation than are vegetable fats and that the changes are diminished by the exclusion of oxygen.

59. When fats are irradiated substances are formed which arise from reactions involving decarboxylation and dehydrogenation of fatty acids, and the movement of double bonds and polymerisation [95]. Many different substances containing reactive carbonyl groups may be formed. For instance when hog-back fat was irradiated with about 10 Mrad the volatile matter was found to include 24 substances which possessed reactive carbonyl groups, of which 13 were saturated and 11 unsaturated. In irradiated lard many aldehydes were detected, including propionaldehyde, butyraldehyde, valeraldehyde, acrolein and crotonaldehyde, while in irradiated oleic acid substances with dicarbonyl groups and alpha-beta unsaturated monocarbonyl groups, containing altogether 2 to 16 carbon atoms, were detected [214, 215].

60. When fat is irradiated with about 5 Mrad the rate of digestion and absorption is slightly reduced [214, 216, 221] but the net nutritive value to the consumer appears not to be significantly altered.

(*d*) *Influence on vitamins*

61. Wide differences have been reported about the extent to which the various vitamins are destroyed by irradiation, though the experimental findings have not always been consistent. It can be said, with caution, that the amount of destruction of vitamins which results from irradiation with up to 6 Mrad is not very different from the destruction that results from cooking, but there are exceptions to this general rule (see Appendix III).

62. As examples of the changes in vitamin content which result from irradiation it can be noted that about 0·4 Mrad has been reported to destroy as much as 70 per cent of the vitamin A and 40 per cent of the carotenoids of liquid milk [109, 164, 290]. With pasteurised liquid milk treatment with 0·1 Mrad has caused a loss of 40 per cent of the thiamine present [4], while 30 per cent of the thiamine present in frozen egg was destroyed by treatment of 0·5 Mrad [153]. Some confusion exists with respect to the influence of irradiation on the vitamin C content of food. Thus some investigators [39, 280] have reported a loss of up to 20 per cent in the vitamin C content when potatoes were treated with 0·01—0·02 Mrad to inhibit sprouting, while others have found no appreciable change on treatment with 0·01 Mrad [230]. In the U.S.S.R. an increase in the vitamin C content of potatoes has been reported to follow treatment with 0·05—0·01 Mrad [86].

63. The evidence concerning the effect of irradiation on the vitamin content of food is reviewed in Appendix III, where the effects of heat and of irradiation are compared. Although the results are not always consistent it can be inferred from Appendix III that with the range of doses of radiation likely to be used in practice the greater the dose of radiation used the greater the loss of vitamin content.

(*e*) *The possible presence of mutagens in irradiated food*

64. It has been reported that genetic changes occur more frequently in the fruit fly *Drosophila melanogaster* when the food on which it subsists has been irradi-

ated [305, 274]. The possibility must be considered that, under the influence of radiation, substances are formed in food which are capable of increasing the natural mutation rate of any form of life. The Working Party has therefore reviewed the evidence for the existence of such chemical mutagens in irradiated food and for any hazard for man that might arise from their presence therein.

65. Evidence that irradiation under specified conditions of a particular type of food always produces mutagens which are capable of enhancing the mutation rate of *Drosophila* does not mean that irradiation of any type of human food would result in the appearance of such substances. Nor could it be assumed that they would be absorbed and reach the human germ cells, and result in alterations in the genetic character of the offspring.

66. The Working Party has concluded that the evidence now available is insufficient to show that substances present in irradiated food would reasonably be expected to act as chemical mutagens in the human being. The Working Party is agreed that if further experimental investigation of the mutagenic action of irradiated food should substantiate the somewhat meagre results at present available this would call for further consideration of the question.

**The nutritive value of irradiated food**

67. The change in the nutritive value of food induced by irradiation with a dose of 5 Mrad or less has, where it has been measured, proved to be very small indeed. In general it seems likely that the loss of nutrients induced by the maximum dose of radiation under consideration in this Report for the treatment of food will be about the same as that induced by standard cooking or canning procedures. The loss of thiamine caused by irradiation may be greater than that resulting from heat treatment, perhaps particularly so with chicken, meat and milk. As much as 60 per cent of the thiamine in milk may be lost as a result of treatment by radiation (Appendix III) and this knowledge, coupled with the fact that at certain ages and in certain states of health milk may bulk largely in the diet, makes clear the need for special scrutiny of proposals relating to any food which makes an important contribution of any nutrient to the national diet. Unfortunately evidence is scanty about the extent to which the destructive effects of irradiation and of heating on vitamins are additive, and since many irradiated foods will need to be cooked before consumption, this question requires much more investigation. Nevertheless when, as with the majority of people in the United Kingdom, a very mixed diet is eaten the inclusion within it of a significant proportion of irradiated food would be unlikely to involve a risk of a lowering of its nutritional value to a much greater extent than it is already lowered by consumption of conventionally heated foods. This means that the national diet, which on the available evidence is satisfactory in its supply of all required nutrients, might reasonably be expected to remain adequate were some irradiated foods included in it, but the considerations above would need to be borne in mind in the examination of specific proposals to irradiate particular foods.

**The examination of irradiated food for the possible presence of toxic susbtances**

68. If significant amounts of radioactive substances appear in food as a result of irradiation they ought to be regarded as potentially toxic but the evidence concerning their possible formation will be considered in a later section of the Report (see paragraphs 82 to 94). The question of the possible production of non-radioactive toxic substances under the influence of irradiation is now considered.

69. The identification of the individual substances formed in food as the result of irradiation is a difficult task. Irradiated meat has been extensively studied, and the following types of substances have been identified. (a) Water-soluble carbonyl-containing substances, probably from protein; (b) *iso*octane-soluble carbonyl-containing substances, mainly long-chain aldehydes and ketones, from plasmalogens and other lipids; (c) volatile bases, mainly methylamine and ethylamine, from non-protein nitrogenous substances; (d) volatile sulphur-containing substances, some of which are normally found in meat but are present in greater amount after irradiation, and substances found only after irradiation, such as methyl mercaptan, *iso*butyl mercaptan and 3-methylthio-propionaldehyde (methional). From the observed changes in odour and flavour the presence of other substances has been surmised.

70. One investigator has commented [214] that there is evidence for the presence in irradiated food "of nearly every predicted carbonyl product of the oxidative disruption of the unsaturated fatty acids common to the tissues studied". Although a detailed study of the toxicology of every substance which appears in food as the result of irradiation may be desirable in theory, it is not a practical proposition. Nevertheless some of the known products of irradiation have been studied. For example, dodecylaldehyde has been fed to groups of rats for 30 days at an intake of 50-100 times the amount ever likely to be present in irradiated food, and no ill effects have been observed [214]. The testing for toxicity, including the long-term effects, of mixed samples of substances formed under the influence of irradiation is being undertaken [312] and also of groups of substances selectively extracted from irradiated food [71].

### The examination of the wholesomeness of irradiated food

71. In this Report the word "wholesomeness" means "nutritional adequacy and safety for consumption", a definition agreed upon at an international conference held in 1961 [95].

72. Because so many substances are formed in food, in small amount, as the result of irradiation, the testing of every substance for toxicity is difficult (paragraph 69). On the other hand many different irradiated foods have been tested for wholesomeness [186, 95]. Such tests with irradiated whole foods have the advantage that the food would contain the sum total of any toxic substances that might be produced by irradiation. In tests on substances proposed as additives to food it is customary to feed to animals one hundred times the amount, weight for weight, expected to be consumed by a human being, and so to show that it is harmless in this amount. This is rarely possible with irradiated whole foods because the amount of any one item of food that would have to be consumed daily by the experimental animal would be much more than it could eat. Tests on animals of the wholesomeness of food treated with one hundred times the dose of radiation proposed for use in the treatment of food intended for human consumption are not necessarily relevant since substances may be formed with large doses of radiation which are not produced to any appreciable extent with small ones. Experiments to test whether or not a hundred-fold margin of safety exists for substances produced by irradiation can therefore be carried out only with substances obtainable in concentrated form, either by extraction from the food or by other means. Since this is possible in only a relatively few instances, most of the investigations have been carried out with whole irradiated foods, the food usually being present in the diet in an amount

which is the maximum tolerated by the experimental animal. For most foods this is proportionately more than the likely long-term average consumption by man.

73. A variety of irradiated meats and meat products, fish, eggs, milk, cereals, potatoes and other vegetables, and fruits, have been fed for up to two years to one or more species of laboratory animal (see Table 2). In tests for palatability and general digestibility human beings have subsisted on irradiated food for up to 15 days. In none of these tests was irradiated food injurious to the species tested (Table 2). In some experiments with food containing a high proportion of irradiated meat, rats displayed a tendency to haemorrhage [146, 207, 259]. This was attributed to vitamin K deficiency which arose partly from the fact that, as a result of consuming the food containing irradiated meat, the rats ceased to practice coprophagy, and were thus deprived of the vitamin K normally synthesised by the bacteria in the gut [192, 193].

74. In the United Kingdom long-term experiments concerning the wholesomeness of wheat treated with low doses of radiation, sufficient to kill any infesting insects [60, 127, 128, 115, 129], of ham treated with radiation in a dose sufficient to prolong storage life [143], and of eggs treated similarly [126], are either complete or in progress. No evidence has yet accrued from these long-term investigations that the treated food is in any way deleterious to the species employed in the test.

75. If a means is discovered of sterilising uncooked food by irradiation under such conditions that the palatability of the food is not adversely affected, the prolonged storage, at room temperature, of uncooked palatable food could become widespread. Certain sterile foods, particularly animal tissues, would be liable to undergo autolysis if stored at room temperature for a long time. Such autolysed sterile tissue might provide safe food for all, but not enough is yet known about the effects of the long-term consumption of it to be certain of this.

**Examination of irradiated food for the possible presence of carcinogens**

76. Some suspicion of irradiated food in this respect arises in theory because irradiation can cause the formation of peroxides, and some sterol peroxides, for example 6 – $\beta$ – hydroperoxy – 4 – cholesten – 3 – one, are carcinogenic in mice. There is, however, no evidence that any of those oxidative products of sterols which are known to be carcinogenic are formed during the irradiation of food. In theory also a risk of cancer could arise from the consumption of irradiated food because certain non-radioactive atoms in it could be converted into radioactive ones if radiation of sufficiently high energy were used. The evidence relevant to the question of induced radioactivity is reviewed in paragraphs 82 to 94 and Appendices I and II. The conclusion there drawn is that no significant risk of this sort exists if any food is irradiated with 6 Mrad or less of ionising radiation with energy up to and including 5 MeV. The Working Party is aware of no other theoretical grounds for considering the possibility that the irradiation of food can induce the appearance of carcinogens but nevertheless believes that the possibility of a carcinogenic hazard should be borne in mind when acceptance for human consumption of any food or group of foods that has been subjected to irradiation is under consideration.

77. Many long-term tests on animals of the wholesomeness of a variety of irradiated foods have been carried out for the Quartermaster of the U.S. Army [186]. Final reports of the results of some tests are not yet available, but no

evidence of any carcinogenic activity of the irradiated food has been recorded. In such tests involving some hundreds of thousands of animals, numerous food products (many of which were mixtures) have either been tested or are still under examination.

TABLE 2

*Table of Wholesomeness Tests*

| *Type of food* | *Treatment* | *Wholesomeness test* |
|---|---|---|
| Beef | 2·79 Mrad<br>5·58 Mrad | a, b, c, d |
| Pork | 2·79 Mrad<br>5·58 Mrad | a, b, c, d |
| Bacon | 2·79 Mrad<br>5·58 Mrad | a, b, c, d |
| Ham | 0·5 Mrad<br>2·0 Mrad | a, b, c, |
| Chicken | 2·79 Mrad<br>5·58 Mrad | a, c, d |
| Fish | 2·79 Mrad<br>5·58 Mrad | a (haddock and tuna)<br>b (cod)<br>d (cod and tuna) |
| Dried whole egg | 2·79 Mrad | a, b, d |
| Milk | 2·79 Mrad<br>5·58 Mrad | a (powdered)<br>b, d, c (evaporated) |
| Cabbage | 2·79 Mrad<br>5·58 Mrad | a, b, d |
| Peaches | 2·79 Mrad<br>5·58 Mrad | a, b, g |
| Potatoes | (1) 1·5 Krad<br>(2) 7·5 Krad<br>(3) 10 Krad<br>(4) 15 Krad<br>(5) 25 Krad<br>(6) 50 Krad | a(5), b(1,2), c(3),<br>d(4,6), f(3) |
| Cereals:<br>Bread<br>Wheat<br>Corn<br>Oats<br>Barley<br>White Flour<br>etc. | 10 Krad – 5·58 Mrad<br>(various experiments.) | a, b, c, d, e, f |

Letters refer to feeding studies involving:

(a) rats (3 months)
(b) rats (lifetime or 2 years)
(c) mice (lifetime)
(d) dogs (2 years)
(e) poultry (6–12 months)
(f) pigs (6 months)
(g) monkeys (2 years)

Human volunteers have also been involved in tests on irradiated whole meals for periods of 15 days. A wide variety of food items was involved.

78. The Committee on Medical and Nutritional Aspects of Food Policy set up a Panel on Carcinogenic Risks in Food Additives and Pesticides in 1958, under the Chairmanship of Sir Charles Dodds. This Panel reported on the principles that should govern "the assessment of hazards from carcinogens (and co-carcinogens) among substances used or proposed to be used as food additives or pesticides" [210]. This report recommended that such substances be tested on groups of both sexes of at least two species of animals by feeding and injection and it was suggested (as a general rule though not as a rigid minimum requirement) that "at least 12 mice in each group should survive for 80 weeks and at least 12 rats in each group for two years . . . In certain cases, such as irradiated foods, . . . oral testing is the only feasible method and larger groups of animals should be used". In few of the reports available for scrutiny by the Working Party do the numbers and longevity of the test animals meet these criteria. Nevertheless many of the investigations have been extensive and no evidence for the carcinogenicity of irradiated food has arisen.

79. In the United Kingdom tests for wholesomeness carried out in the laboratories of Unilever Limited with ham, irradiated with 2 Mrad of gamma radiation from cobalt-60, in the frozen state at —12°C and stored at this temperature, completely fulfilled the requirements recommended by the Panel on Carcinogenic Risks in Food Additives and Pesticides, which has been reconstituted as the Standing Panel on Carcinogenic Hazards in Food Additives and Food Contaminants. The Working Party sought the comments of the reconstituted Panel, now under the Chairmanship of Professor Alexander Haddow, on the report of the investigations provided by Unilever Limited, with the result that the following statement was received:—"The Standing Panel on Carcinogenic Hazards in Food Additives and Food Contaminants considered that the evidence submitted by Messrs. Unilever Limited provided an adequate basis for the conclusion that ham irradiated with 2 Mrad at a temperature of —12°C would present no carcinogenic risk to man if offered for sale as human food. This opinion could not necessarily be extended to ham irradiated at other and, especially, at room temperature."

80. Caution is needed and no general statement can be made that carcinogenic substances never exist in food irradiated under the conditions considered in this Report. But equally well the general statement could not be made that carcinogenic substances are absent from all unirradiated food, including that cooked by conventional methods. All that can be said at the present time is that the many and extensive investigations that have been carried out on irradiated foods have yielded no evidence that a risk of cancer would arise from the consumption of any of them.

**Examination for the presence of induced radioactivity in food**

81. It should first be emphasised that radioactivity is not a peculiar, isolated phenomenon, observed only in very special circumstances, but is widespread, and almost certainly has been so ever since life existed on Earth. All matter which is examined for radioactivity yields a positive test, and there exist naturally radioactive elements in food, in which isotopes of potassium ($^{40}K$), carbon ($^{14}C$) and hydrogen (tritium $^{3}H$) predominate, while radium ($^{226}Ra$) is a trace constituent of many foods. In the healthy human body there are many thousands of atomic nuclear disintegrations occuring each second, these being largely attributable to the presence of naturally radioactive potassium and

carbon. In fact, the human body possesses about 135 millimicrocuries of radioactivity under normal conditions — equivalent in radiation energy to about 15 millimicrograms of radium. Each day the intake of naturally radioactive material in normal food is about 3 millimicrocuries, that is an amount equivalent to about 2 per cent of the total radioactivity in the normal human body.

(*a*) *The possibility that irradiation can induce radioactivity in food by stimulating the ejection of a nuclear particle*

82. It was pointed out in paragraph 27 that the atomic nuclei in irradiated matter may be excited by the absorption of energy from the incident radiation to such an extent that the excited nucleus may eject a particle, being thus transformed into a new nucleus that may or may not be radioactive. Whether or not ejection of a nuclear particle can be induced depends upon the nature of the atomic nucleus which is excited, and upon the energy of the exciting radiation. Radiation of energy 10·5 MeV or more can induce the nucleus of an ordinary nitrogen atom ($^{14}N$) to eject a neutron with the production of a radioactive isotope of nitrogen. With ordinary oxygen ($^{16}0$) the lower limit of energy needed in the exciting radiation to induce an analogous effect is 15·5 MeV, while with ordinary carbon ($^{12}C$) it is 18·8 MeV. The radioactive isotopes of nitrogen, oxygen and carbon which can thus appear under the influence of radiation of sufficiently high energy are short lived, their half-lives, that is the time during which one half of the radioactivity is lost, being 2—21 minutes. With hydrogen ($^{1}H$) no such radioactivity can be induced even with radiation of very high energy. It is clear that, for radioactivity to be induced in this way, the nuclei of the common elements of food need excitation with radiation of energy well above the upper limits (5 MeV) of that under consideration of this Report for the general treatment of food (see pargaraph 133). Nevertheless the nucleus of the element lithium ($^{7}Li$), which may be present in food in minute amounts, can respond to radiation of energy of about 2·5 MeV with the ejection of an alpha particle and the formation of the radioactive isotope of hydrogen known as tritium ($^{3}H$), which has a half-life of about 12 years.

83. When an atomic nucleus is excited by radiation to eject a neutron the nucleus which remains may or may not be radioactive. In either case the ejected neutron may be capable of inducing radioactivity in the nucleus of an atom of another kind by entering this nucleus and remaining there. This mechanism of inducing radioactivity is referred to as 'neutron activation'. Radioactivity may thus be secondarily induced as a result of irradiation when the radiation excites any nucleus to eject a neutron, whether or not the nucleus which has lost the neutron has become radioactive itself.

84. With radiation of 5 MeV there are four nuclei which could be sufficiently excited to eject a neutron, and which might be present in food in minute amount. In each instance the nucleus which remains is not radioactive. The four elements concerned, and the energy of the radiation needed to excite their nuclei sufficiently to cause the ejection of a single neutron, are:—(1) deuterium ($^{2}H$) a rare stable isotope of hydrogen (2·2 MeV); (2) beryllium ($^{9}Be$) (1·7 MeV); (3) the rare stable isotope of carbon ($^{13}C$) (4·9 MeV); (4) the rare isotope of oxygen ($^{17}O$) (4·1 MeV). About 0·02 per cent of natural hydrogen consists of deuterium, about 0·04 per cent of natural oxygen is the isotope $^{17}O$ and about 1·1 per cent of natural carbon is $^{13}C$; similar proportions of these rare isotopes are present in the hydrogen, oxygen and carbon of food. Beryllium is not normally regarded as present in food even in trace amounts, though it might be found in

any metallic copper used in the construction of a plant used for the irradiation of food. Traces of beryllium might possibly be found in some types of container used to hold food undergoing irradiation, though this is unlikely.

85. With radiation of 7 MeV the effect is little different from that of 5 MeV, but with 10 MeV radiation the number of possible reactions is significantly greater [275]. With radiation of energy about 10·5 MeV the nitrogen of food becomes reactive (see paragraph 82 above) and with radiation of energy 15 MeV the number of susceptible elements is very large [275].

86. Calculations based on highly pessimistic assumptions about the amount of susceptible elements in food indicate that 24 hours after irradiation with 10 MeV electrons the radioactivity induced by neutron activation would be only about 1 per cent of that expected naturally and that the increase with 10 MeV X-radiation would be about 30 per cent of the intrinsic radioactivity of the food [275].

(*b*) *Induced radioactivity resulting from isomer activation*

87. It was pointed out in paragraph 28 that a nucleus excited by radiation may remain in an excited state without emitting a particle. Such a metastable nucleus, which is said to have undergone isomer activation, ultimately loses its extra energy by emitting gamma-radiation; it is therefore radioactive. Induction of radioactivity by isomer activation of some atomic nuclei can be effected by radiation of energy as low as 1 MeV, or even below. But such induction of radioactivity does not occur at all with the common elements of food, though it is known to occur with some elements which would be expected to be present in trace amount. Strontium ($^{87}Sr$), tin ($^{117}Sn$ and $^{119}Sn$), barium ($^{135}Ba$) and cadmium ($^{111}Cd$ and $^{113}Cd$) are elements which fall into this category.

(*c*) *Assessment of the total induced radioactivity to be expected in food under different conditions*

88. A quantitative assessment of the amount of induce radioactivity that could be expected to appear in food as the result of treatment with radiation of different energies would be of great value. Mr. F. Rogers of the Wantage Research Laboratory of the Atomic Energy Research Establishment has recently published an assessment of this sort. The Working Party is permitted to quote *verbatim* below the Abstract of this publication [275]:—

> "In order to estimate the possible extent of the radiation hazard which might arise from the irradiation of food a survey of relevant nuclear reactions has been made. Semi-empirical formulas, derived from published determinations of activities induced in a number of nuclides, were used to calculate activities due to similar reactions in other nuclides. Irradiation by cobalt-60 gamma rays and by 5, 7, 10 and 15 MeV electrons and X-rays was considered. These results were combined with independent estimates of the maximum concentrations of the elements which could credibly exist in a diet, giving upper limits for the activities which might be induced. More typical concentrations of the elements were used in a separate series of calculations. Since the activities in terms of curies are not biologically comparable, they were expressed as fractions of the maximum permissible concentrations in drinking water for the public use.
>
> "The estimates must be viewed in relation to the postulated concentrations of the elements. In the case of the 'maximum credible concentrations' the highest of several opinions was taken for each element".

89. Mr. Rogers' report makes clear that the radioactivity induced as the result of irradiation of food is predominantly of short half-life. If the natural radioactivity in food is considered to be approximately that of the maximum credible concentration of potassium accepted by Mr. Rogers ([275] — Tables [I] and [III]) then the calculated induced radioactivity can be expressed as a percentage of the natural radioactivity of food. With gamma-radiation from cobalt-60, isomer activation only is probable (see paragraph 28 above), and 24 hours after irradiation the maximum induced radioactivity is only about 0·00005 per cent of the natural radioactivity in food. With 5 MeV electrons the comparable figure is 0·025 per cent. Such assessments are, of course, based on pessimistic assumptions about the maximum concentration of certain elements in foods. From typical figures for the composition of meat and vegetables the results set out in Table 5 of Appendix II can be obtained. If the natural radioactivity of meat and vegetables is considered to be due to their expected content of potassium, calculation indicates that with 7 MeV and 10 MeV electrons the induced radioactivity 24 hours after irradiation is around 0·1 per cent of the expected natural radioactivity of food. With X-radiation the figure is 5 to 10 per cent. The figures in Table 5 suggest that with 15 MeV electrons the induced radioactivity 24 hours after irradiation is around 2 to 5 per cent of the natural radioactivity, the figure for X-radiation being 50 to 100 per cent.

90. Although some of the assumptions which underlie the foregoing quantitative considerations are arbitrary the Working Party believes them to demonstrate that when food is treated with 6 Mrad of ionising radiation of 10 MeV or less the maximum induced radioactivity 24 hours after irradiation is likely to be only a small fraction of the radioactivity already naturally present in the food. The total radioactivity of food irradiated under such conditions is therefore likely to be less than the maximum which would be encountered naturally as the result of normal variations in the intrinsic radioactivity of food. Although the consumption of irradiated food is unlikely to take place within 24 hours of its treatment the Working Party think that precautions against this unlikely event ought to be considered, in view of the information in Mr. Rogers' report [275], if the irradiation of food is developed on a large scale.

91. No measurable increase in radioactivity of food has so far been detected as the result of treatment of it with ionising radiation of 10 MeV or less [333, 102, 103, 202].

92. When food is treated with 5 MeV electrons the calculations summarised in Table 4, Appendix II, suggest that, under the most unfavourable conditions, 24 hours after irradiation the induced radioactivity would be only about 0·03 per cent of that naturally present in food. The corresponding figure for X-radiation is 2 per cent. The Working Party concludes that such an increase, which is within the limits of the natural variations expected in the intrinsic radioactivity of food, would involve no hazard to the consumer of the food.

93. Despite the fact that no induced radioactivity has so far been detected in food which has been irradiated with ionising radiation of energy 10 MeV or less, the calculated figures in Appendix II suggest that 24 hours after treatment with 10 MeV ionising radiation the induced radioactivity could be found to be, if the measurements were feasible, about one-hundred times that observed in a similar period after treatment with radiation of energy 5 MeV. This consideration led the Working Party to adopt a cautious view concerning the hazard from induced radioactivity which might be expected from treatment of food with ionising radiation of energy above 5 MeV. The figures in Table 5 indicate

that 24 hours after the irradiation of meat or vegetables with 10 MeV radiation no measurable induced radioactivity would exist, and that no hazard would be expected from the consumption of the food. But it is clear from Mr. Rogers' report that this need not necessarily be so with all foods, and the Working Party agreed that if any food is treated with radiation of energy greater than 5 MeV, the question of hazard to the consumer from induced radioactivity should be carefully considered in each specific instance.

94. The possibility that significant radioactivity might be induced in the container of the food undergoing irradiation has been considered. There is no evidence to suggest that a hazard is likely to occur in this respect if the radiation energy is limited to 10 MeV but it seems desirable that a complete analysis of the chemical composition of containers proposed for use in this connection should be available for scrutiny with these possibilities in mind, and that in practice tests should be carried out to ensure that no detectable induced radioactivity exists in the containers of food as the result of irradiation.

### The possible influence of radiation on permitted food additives

95. Permission to add a substance to food with the object, for example, of prolonging storage life, is granted only after exhaustive investigation of the possible toxic effects of the proposed additive. The possibility exists that, under the influence of radiation, permitted additives might be transformed into less desirable substances. Under bacterial action the conversion of nitrite to nitrite occurs in the curing of ham, bacon and other meats, and insofar as statutory limits apply, these have been related to nitrite and are incorporated in Regulations ([302] — regulation IV(f)). A similar conversion of nitrate to nitrite occurs under the influence of irradiation and under the Regulations it would thus be necessary for producers of irradiated food which contained nitrate to take account of the amount of nitrite present in the final product. The Working Party concludes that no toxic hazard is likely to arise from the addition to meat of nitrite in the permitted amount, if the meat is irradiated, but that the influence of irradiation on other permitted additives should be reviewed, and if necessary ascertained experimentally, before foods for human consumption which contain them are irradiated.

## THE MICROBIOLOGY OF IRRADIATED FOOD

### The influence of ionising radiation on micro-organisms

96. The action of a small dose of ionising radiation on living cells is usually much greater than might be expected from the extent of the observed chemical change. The unexpectedly big effect of radiation on living cells appears to arise from the sensitivity to it of intracellular deoxyribonucleic acid, and the related substance, ribonucleic acid, which together influence cellular reproduction and the synthesis of protein upon which reproduction depends. When a microorganism dies as a result of treatment with, for example, 6 Mrad or less of radiation, death may not occur immediately after irradiation, but at or following the next reproductive division of the cell [169]. Usually the cells injured by radiation can still reproduce by division, but once only, and if the resulting daughter cells are unable to divide, they ultimately die. The genetic character of the daughter cells may differ from that of the parent because the genetic substance, deoxyribonucleic acid, has been altered by the action of the radiation

on the parent cell. Such an alteration in genetic character is described as a "mutation", and if the daughter cells are able to divide, so that the newly induced strain of micro-organism can proliferate, the new strain is referred to as a "mutant" strain.

97. When food containing millions of micro-organisms is irradiated, even though the conditions are such that millions of them are so affected as to die, it has been argued, on mathematical grounds, that a few by chance may survive. A similar chance of survival of micro-organisms exists when food is treated by heat in a conventional manner. Even though it is theoretically impossible to ensure that every micro-organism in food is destroyed either by conventional treatment with heat or by irradiation, nevertheless, in practice it may be impossible to reveal the presence of surviving micro-organisms in food treated under suitable conditions, in the great majority of any examinations made for their detection. The appropriate application of heat or of radiation can therefore reasonably be expected to ensure sterility in the vast majority of samples of food to which the appropriate treatment is applied.

98. In the assessment of the influence of treatment with heat or with radiation on the number of micro-organisms found in food (or in any other material) it is useful to refer to a "D value" for each type of micro-organism. The "D value" is the dose of radiation (or for heat — the time at a certain temperature) which will leave 10 per cent survivors, and varies with the strain of micro-organism and the chemical and physical conditions. From the "D value" an "inactivation factor" can be calculated; this is the number of organisms which when subjected to a given treatment, would be expected to be reduced to one survivor. The "D value" for *Cl. botulinum* Type A is 0·4 (Table 3). Therefore when this organism is treated by 5 Mrad the inactivation factor will be the $5 \div 0{\cdot}4$ power of 10, that is $10^{12{\cdot}5}$. The other inactivation factors given in Table 3 are calculated similarly. One particularly radiation-resistant vegetative micro-organism has been isolated from irradiated meat; it is called *Micrococcus radiodurans* and it is non-pathogenic. With this organism a dose of 5 Mrad would result in an inactivation factor of about the same order as that achieved for *Cl. botulinum* type A, and it has been suggested as a test organism for radiation-sterilised foods [80]. For *Cl. botulinum* the necessity of an inactivation factor of $10^{12}$ is widely accepted in the canning industry as providing an acceptable measure of safety for treatment by heat. The proof of the effectiveness in practice of adherence to this factor is illustrated by the fact that confirmed botulism has not occurred for more than 25 years as the result of the consumption of food canned in the United Kingdom. The Working Party adopts the view put forward by Schmidt 1961 [283] that "radiation-sterilised foods must be equal in public health safety to thermally processed foods which means that the minimum radiation-sterilising dose should bear the same relation to the maximum radiation resistance of spores of *Cl. botulinum* as the accepted minimum thermal process bears to the maximum thermal resistance of the spores of this organism." The minimum dose of radiation that fulfils this criterion is 4—5 Mrad.

99. It is not easy to set out a comparable simple table to compare the destructive effect of heat on different strains of micro-organism, since the effects of heat depend both on the temperature and on the period of heating. But much is known about the relative resistance to heat of *Cl. botulinum* on the one hand and of spore-forming organisms which can spoil food on the other. For example,

3·6 minutes at 121°C is calculated to yield an inactivation factor for *Cl. botulinum* of $10^{12}$, for *Cl. sporogenes* of about $10^4$ and for *B. Stearothermophilus* of $10^1$. Although *Cl. botulinum* is the most resistant to irradiation of any known pathogen (Table 3) it is, as shown above, much more sensitive to destruction by heat than certain other organisms. This difference has obvious implications with respect to the relative safeties of sterilisation by heat and by irradiation (see Appendix IV and paragraph 102).

TABLE 3

*'D Values' *, and Inactivation Factors at 0·5 and 5·0 Mrad, for various micro-organisms*

(Data calculated from various sources)

| *Micro-organism* | *Medium* | *D Value (Mrad)* | *Inactivation Factor at* 0·5 *Mrad* | 5·0 *Mrad* | *Reference* |
|---|---|---|---|---|---|
| *Cl. botulinum* Type A | Food | 0·40 (max) | $10^1$–$10^2$ | $10^{12}$ | 283 |
| *Cl. botulinum* Type B | Buffer | 0·33 | $10^2$ | $10^{15}$ | 5 |
| *B. pumilus* | Buffer anearobic | 0·30 | $10^2$ | $10^{17}$ | 177 |
| *M. radiodurans* $R_1$ | Beef | 0·25 | — | $10^{12}$† | 80 |
| *Cl. welchii* | Meat | 0·21–0·24 | $10^2$ | $10^{24}$–$10^{21}$ | 197 |
| *Cl. sporogenes* | Buffer | 0·21 | $10^2$–$10^3$ | $10^{24}$ | 5 |
| *Cl. botulinum* Type E | Broth | 0·20 | $10^3$ | $10^{25}$ | 90 |
| *B. pumilus* | Buffer, dry, aerobic | 0·17 | $10^3$ | $10^{29}$ | 177 |
| *B. stearothermophilus* | Buffer, aerobic | 0·10 | $10^5$ | Greater than $10^{30}$ | 177 |
| *S. typhi-murium* | Frozen egg | 0·07 | $10^7$ | „ | 174 |
| *S. faecalis* | Broth | 0·05 | $10^{10}$ | „ | 90 |
| *S. typhi-murium* | Buffer, aerobic | 0·02 | $10^{25}$ | „ | 174 |
| *E. coli* | Broth | 0·02 | $10^{25}$ | „ | 90 |
| *Pseudomonas sp.* | Buffer, aerobic | 0·004 | Greater than $10^{30}$ | „ | 24 |

* Dose which leads to the reduction of an initial population to 10 per cent survivors.

† In this instance the calculation of the inactivation factor from the D value is complicated by the fact that the survival curve of the micro-organism is abnormal. The abnormality has been taken into account in the calculation of the inactivation factor at 5 Mrad.

100. The evidence concerning the influence of ionising radiation on foodborne viruses is meagre but studies with viruses in other media have indicated that they are less susceptible to damage by radiation than are many micro-organisms

[239]. In the discussion of the microbiology of irradiated food any evidence relating to ultra-filtrable viruses or other infective agents will be included in the relevant section.

**Definition of Sterilisation**

101. Because of the considerations cited in the preceeding paragraphs, the Working Party defines "sterilisation" as the reduction of the number of all contaminating organisms in food to such an extent that none is detectable in the treated food by any recognised method, no matter how long or under what conditions the food is stored in the absence of recontamination. The pathogens and putrefactive organisms most resistant to the destructive effects of the sterilising treatment clearly need special consideration. With the possible exception of *Micrococcus radiodurans* (paragraph 98), *Cl. botulinum* in spore form is the least sensitive to destruction by irradiation of all the micro-organisms likely to be present in food (Table 3).

102. The fact that spores of *Cl. botulinum* are more resistant to the destructive effects of radiation than those of organisms normally responsible for the spoilage of food is seen to be a particular disadvantage to any proposed industrial application of radiation to the treatment of food. If irradiation proves to be nearly but not quite effective in sterilising food already contaminated with spores of *Cl. botulinum*, the remaining microflora could consist largely or wholly of *Cl. botulinum*. If the conditions of subsequent storage of the irradiated food permitted the germination of these spores and the growth of the organism, the production of *Cl. botulinum* toxin would not necessarily be associated with the activities of those other organisms which normally warn of bacterial hazard.

**Definition of Pasteurisation**

103. In Appendix IV paragraph 1 it is explained that the process of heat treatment as first devised by Pasteur had as its aim the control of spoilage organisms, but that "pasteurisation" by heat was later developed for public health purposes for the destruction in certain foods of pathogens such as *Mycobacterium tuberculosis*. The Working Party has used the term "pasteurisation" to cover either the control of the spoilage organisms or of the pathogens which are most likely to be troublesome or dangerous in the food that is to be irradiated. Examples of the first use of the term are the reduction of the numbers of organisms on meats and fish and of the moulds on fruit, such as strawberries; the doses required in these applications are in the range up to 1·0 Mrad. An example of the use of irradiation for pasteurisation with respect to pathogens is the treatment of frozen whole egg to reduce the number of *Salmonellae*. Irradiation with 0·5 Mrad provides an inactivation factor of $10^7$ for the most radiation-resistant strain of *Salmonellae* so far encountered [174].

104. Heat pasteurisation has troublesome limitations because of the impossibility of ensuring an even distribution of temperature throughout a solid object by the application of heat from the outside. With radiation, on the other hand, the penetrating power is greater (Appendix 1); the chances of even distribution of the deposited energy throughout the mass of the food are therefore much greater than with heating, and for this reason alone the application of ionising radiation for the pasteurisation of solid foods on an industrial scale might become more attractive than the application of heat for this purpose has ever been. The question of microbial hazards which might then arise needs careful

consideration. It should be emphasised at this point that heat pasteurisation has not been allowed for the masking of spoiled or highly contaminated food. This principle is accepted, for example, in Regulations [300] requiring that milk should be produced and handled in hygienic conditions even though about 96 per cent of milk sold by retail is heat-treated before sale. Equally irradiation should not be permitted to be a substitute for good hygiene nor should irradiated food be handled with fewer hygienic precautions than other types of food.

**Combined treatments for the control of micro-organisms**

105. The control of micro-organisms may be achieved by a combination of irradiation with other treatments, for example treatment by heat or by the addition of preservatives. Irradiation renders some micro-organisms more susceptible to destruction by heat, so that a combination of irradiation with heat may have special advantages. In some instances a judicious use of heat and irradiation can ensure sterility when a dose of radiation of 1 Mrad or even less is used.

106. Further research may lead to the discovery of ways of treating food before irradiation which render the spores of any micro-organism present in the food, and particularly those of *Cl. botulinum*, more sensitive to destruction by irradiation. Such a development would ensure sterilisation as the result of treatment with less than 5 Mrad and would correspondingly reduce the radiation produced changes in palatability. Substances are already known which sensitise some bacteria to the destructive effects of radiation [294] but the value of the use of such substances in practice remains to be demonstrated. Such matters for possible future development clearly do not affect the present situation. For every proposed multiple treatment the organism most resistant to destruction by the combination would have to be ascertained, and the conditions needed for attainment of the appropriate inactivation factor determined.

**Effects on bacteria of pasteurising doses of irradiation**

107. If pasteurisation, as opposed to sterilisation, is the aim of irradiation, or if intended sterilisation is not effective, the activities of surviving micro-organisms might expose the consumer to the hazards of microbiological origin outlined in the following paragraphs (*a*) to (*d*):—

(*a*) Mutant strains of micro-organisms might appear. Such mutant strains might possess novel pathogenic properties or might not generate normal indications of bacterial spoilage and thus deprive the consumer of the warning of danger that is normally given by taint and odour.

(*b*) Some micro-organisms might proliferate more readily in irradiated foods than they do in unirradiated food.

(*c*) As a result of the almost complete destruction of the normal micro-flora by irradiation unusual strains of micro-organisms might so flourish, in the virtual absence of competition, that the normal indications of bacterial spoilage, such as taint and odour, might fail to develop. If this were so, harmful results could follow the consumption of apparently uncontaminated food.

(*d*) Pathogens might survive irradiation in sufficient number to allow their rapid and unusual proliferation in the virtual absence of other microbes, the latter having been destroyed by the radiation.

108. There is good evidence that in some instances irradiation can increase the rate of appearance of mutant strains of the micro-organisms which may ordinarily be present in food. But there is no indication that hazard can arise from the appearance of novel strains of pathogenic organism induced by such a means. A statement has been made [91] that after irradiation an innocuous staphylococcus became a virulent coagulase-positive one, with a consequent change in its phage-typing pattern. But it was by no means clear from the evidence published that treatment with radiation was responsible for the change.

109. Organisms more resistant to irradiation can thus appear as a result of radiation-induced mutation. A significant rise in resistance to the destructive effects of irradiation can be induced only in certain strains of micro-organisms and then only by repeated sub-lethal doses of radiation [91]. Highly resistant forms would be likely to arise only as the result of repeated irradiation and in industrial practice food would almost certainly not be treated by radiation more than twice (see Appendix I). Nevertheless repeated exposure of ambient micro-organisms at the plant where irradiation was carried out might induce resistance to the lethal effects of radiation by a process of natural selection. This consideration emphasises the importance of maintaining a high standard of hygiene in such a place.

110. No evidence has been found that irradiation can increase the virulence of pathogenic organisms, though a strain of *Cl. botulinum* has been described [91] which before irradiation was tending to lose its power to form toxin on repeated subculture but which after treatment with radiation maintained its potency in this respect.

111. There is some evidence that substances might develop in food as the result of irradiation which increase the rate of mutation in those micro-organisms which may appear, or which may already be present, in the food [35, 304, 94]. No evidence that a hazard to health is likely to result from such an irradiation-induced change in the food has been found and in the view of the Working Party this possibility is so remote that in the absence of further and direct evidence it can be neglected at the present time.

112. In contrast to these essentially negative conclusions the Working Party takes the view that a significant hazard can arise, under some conditions, from the circumstances outlined in paragraph 107(*d*). The figures in Table 3 indicate that both *Clostridium botulinum* and *Clostridium welchii* could survive treatment by irradiation which was sufficient to destroy normal food spoilage organisms, of which *Clostridium sporogenes* would be taken as a typical example. Under some conditions therefore pathogens could survive in irradiated food unaccompanied by the micro-organisms which produce the substances which, in spoiled food, warn of bacterial hazard. Food of this sort might lack unpleasant taints and odours, and the presence of the sweet, sour or yeasty odours, which could be present in such circumstances, might not cause rejection of the harmful food. The importance of these considerations led the Working Party to review the relevant characteristics of the two pathogens which are known to be relatively resistant to the destructive effects of ionising radiation, namely *Cl. botulinum* and *Cl. welchii*, and also cognate information about simpler infective agents such as ultra-filtrable viruses. Appendix IV sets out the relevant characteristics of the micro-organisms. Below, the Working Party considers whether the chances of poisoning or infection by these infective agents is likely to be enhanced by the irradiation of food.

**Clostridium botulinum**

113. Ingestion of the toxin produced by *Cl. botulinum* causes botulism which is often fatal. The condition is rare in this country but for reasons discussed in Appendix IV this will not necessarily always be so, particularly with respect to Type E, which has recently been reported in outbreaks in several countries. In the same Appendix it is pointed out that, although the *clostridia* are not rare, botulism occurs only if several conditions operate in conjunction. Growth is favoured by anaerobic conditions but will not take place at pH 4·0 to 4·5 or less, nor in a concentration of 8 per cent or more of salt. The spores are resistant to moderate cooking temperatures, particularly Type A. Type E is less resistant, but survives temperatures sufficient to kill many vegetative spoilage organisms. The toxin itself is heat labile to an extent which varies according to the type of organism. Recent work shows that two minutes heating at 60°C is sufficient to inactivate the toxin of Type A, 70°C is sufficient for the toxins of Types B and E, and 90°C for Types C and D. The toxin of the rare Type F is stated to be extremely heat labile. Type A will grow slowly at 10–15°C, i.e. at or below that of many larders in Britain at some times in the year, and Type E can grow and produce toxin at temperatures down to 3·3°C. Though the spoilage of food produced by the organism itself may be slight, its growth in food is usually associated with growth of spoilage organisms which produce odours and taints sufficient to warn the would-be consumer of danger, or cause rejection of the food; this is clearly not invariably the case since otherwise botulism would be even less common than it is.

114. An increased hazard of botulism might therefore arise, if as a result of pasteurisation by radiation, food were to be rendered either less aerobic or less acid, or liable to be subsequently less thoroughly cooked, or stored in a warmer place or for a longer period, or less contaminated with spoilage organisms. No hazard would arise if there were a break in the chain of conditions necessary for the development of botulism, but radiation might have the effect of completing a chain of conditions that would otherwise have been incomplete.

115. Because most or all food that is irradiated will be enclosed within an impermeable container or wrapper, anaerobic conditions are favoured. Nevertheless there is normally an oxygenated zone in meat which extends to a depth of about only 5 mm. so that more deeply deposited organisms could grow readily. Even so the enclosure of food in an airtight container would, in some circumstances, provide a link which might otherwise be missing from the chain of necessary conditions. If radiation were used as an alternative to vinegar or salt as preservatives more favourable conditions for the growth of *Cl. botulinum* might be provided.

116. The conditions set out in paragraph 113 above are conveniently considered together here. If the storage of food is to be prolonged (and this is one of the aims of pasteurisation by radiation) much of the normal spoilage flora must be destroyed. The food might then be storable for a longer period or at a higher temperature than otherwise would be possible, without developing warning tastes or odour. If the spores of *Cl. botulinum*, which are resistant to irradiation, had survived and germinated, the resultant food could be highly dangerous, but in most instances it would be cooked before consumption. In many instances this would destroy the toxin and render the food safe. Nevertheless not all forms of cooking are sufficient to ensure the destruction of all *Cl. botulinum* toxin. This is shown in the experiment with steak described in Appendix IV, paragraph 12. Steak is not the only food that is liable to be eaten

undercooked, and indeed with an increase in taste for cosmopolitan fare, a great number of foods capable of causing botulism may well be eaten, either raw or with a minimum of heating, whether or not irradiation is introduced as a means of prolonging storage.

**Clostridium welchii**

117. The conditions favouring the growth of *Cl. welchii* are in many respects similar to those which favour *Cl. botulinum* but the toxin produced in food by *Cl. welchii* is not destroyed by ordinary cooking. Between 1957 and 1961 in the United Kingdom there were 70 reported outbreaks of *Cl. welchii* enteritis and none of botulism.

118. In any consideration of the question whether pasteurisation by irradiation could contribute to the hazard of *Cl. welchii* enteritis the critical conditions are those to which the food pasteurised by irradiation may be subjected after retail sale. Even though *Cl. welchii* may be among the few surviving organisms in the food, the latter should not at any time before retail sale have been at a temperature above 15°C, which is the minimum required by common strains of *Cl. welchii* for growth, if the risk of *Cl. welchii* enteritis is to be avoided.

119. The possibility cannot therefore be dismissed that such enteritis might arise if these conditions were not fulfilled, and the other conditions associated with this type of food poisoning also held, because irradiation would allow the food to be stored for a longer period without going bad. But the amount of toxin produced would be small and the hazard, in so far as it exists, appears likely also to arise from the consumption of foods which have been pasteurised by heat.

**Ultrafiltrable viruses**

120. Food has occasionally been recognised as a vehicle of transmission to man of a disease caused by infection with an ultrafiltrable virus, though its potentiality in this respect has not been intensively studied. Heating in aqueous medium to 55–60°C for 30–60 minutes destroys many ultra-filtrable viruses [318] but such conditions of heating are not necessarily fulfilled during any cooking that food may receive. Under some conditions certain viruses pathogenic to man are destroyed, in aqueous medium, by irradiation with 1 Mrad but other viruses can survive such treatment.

121. The Working Party has considered the question of whether the use of radiation for the treatment of food is likely to enhance a hazard of virus origin which is at present small and perhaps negligible. Ultra-filtrable viruses are most unlikely to be able to multiply in food under any conditions, so that the manner of storage of irradiated food is not germane in this respect. No evidence has been found that irradiation can increase the virulence of any virus present in food and since radiation in moderate dose is able to destroy at least some viruses it is reasonable to expect that the irradiation of food will diminish, and certainly not enhance, any hazard, slight though it may be, that already exists from the transmission to man through food of any infective virus responsible for ill health.

**The hazard viewed in perspective**

122. Particular attention has been paid in the foregoing discussion to the hazards which might possibly arise from the use of irradiation for the purpose of pasteurisation. But many foods are already on the market after mild treatment

with heat in order to destroy the bulk of the spoilage organisms and thus to prolong storage life. The chances of the survival of *Cl. welchii* or even of *Cl. botulinum* in such foods are probably similar to those for the same organisms in food pasteurised by irradiation. Foods receiving such treatment with heat are not necessarily labelled pasteurised; they may sometimes be described as "ready cooked". The main safeguard against bacterial hazard is that they may be kept frozen up to the time of retail. The hazard provided by irradiation-pasteurised food might well be less than that with such heat-treated foods since spores are perhaps more likely to be activated by mild heat than by mild irradiation. The evidence on this point is incomplete, but will be considered further in paragraph 136.

123. The Working Party saw no profit in considering every possible use of irradiation in relation to every available foodstuff. Many uses of radiation already worked out experimentally might not prove industrially attractive. But there are some foods and some treatments that would, and some that might not, be wholly free from microbiological hazard. The aim of the Working Party has been to indicate the nature of the scrutiny which will be required if and when concrete proposals for irradiation of food intended for human consumption are put forward.

## DISCUSSION

124. The treatment of food by irradiation is as new and as strange to most people as the cooking of food, and its results, must have seemed to our early forebears. At present the evidence that food treated by radiation is never harmful is not so complete as might ideally be required, but had we assembled at the Dawn of Time to consider the safety of cooked food the available evidence would have been much less satisfactory, and indeed is still incomplete. The conditions under which food treated by heat is safe for consumption have slowly been revealed over the ages as the result of trial and, indisputably, of error. Evidence about the limits of possible variation in the composition of food, particularly with respect to trace elements, is still very incomplete. Moreover the fate of many such elements in the human body is imperfectly understood, and the changes in the organic constituents brought about by the cooking of food, and the differences in such changes associated with the possible variations in the composition of food and in the methods of cooking, are matters about which no generalisation can at present be made. Be that as it may it is our duty to try to make such recommendations that the conditions for the safe consumption of irradiated food can, if they exist, be established without the penalties of error, the painful experiences of history being avoided by scientific deduction.

125. Although the irradiation of food at first promised much to many, the early bright hopes have not been fully realised. Means have not yet been found to avoid the troublesome taints usually associated with the application of sterilising doses of radiation, and because of this attention has been frequently directed towards milder treatment, aimed at the elimination of those pathogens and spoilage organisms whose presence constitutes a special disadvantage in particular foods.

126. The advantages which could follow the development of the industrial irradiation of food in the United Kingdom have been discussed (paragraphs 34, 35, 36) in relation to the possible uses of irradiation indicated in Table 1.

The list in Table 1 is likely to be much expanded in time, and although the immediate benefit of the industrial development will largely be with the food manufacturer and distributor there is no doubt that a process which prolongs the safe storage life of food must of necessity be of benefit to the consumer in the long run.

127. The hazards to health which, in the view of the Working Party, could possibly arise from the consumption of irradiated food have already been considered in paragraphs 46–95, and are briefly reviewed below. Many of these possible hazards appear on examination to be negligible if food is irradiated under controlled conditions but rigid definition of the procedures to be adopted for the irradiation of food intended for human consumption may well be needed to ensure that the chances of hazard of any sort are reduced to negligible proportions. For this reason alone control over the irradiation of food is desirable. Moreover because of the newness of irradiation as a method of treatment of food intended for human consumption, and because of the unpleasant associations which the very word "radiation" now often carries, the wide acceptance of this method for the treatment of food may be slow. In the early stages of the industrial use of this new process a single irresponsible or ignorant action by a manufacturer could bring the irradiation of food into lasting disrepute. If the principles are established on which such a control could be based the Working Party hopes that the attainment of some degree of international uniformity in the regulation of the process may be assisted.

**Possible hazards from the consumption of irradiated food**

**Destruction of nutrients**

128. When food is irradiated with 6 Mrad of radiation of energy 5 MeV or less the destruction of nutrients as a whole is roughly the same as that which occurs when safe preservation of the food is ensured by preliminary heating. Irradiation does not cook the food, so many foods treated in this way are likely to be heated before consumption; evidence about the further losses in nutrients that is to be expected when food prepared for preservation by irradiation is later cooked, is limited, but indicates that a small superadded loss of some vitamins is to be expected (Appendix III).

129. In general it seems most unlikely that the inclusion within a mixed diet of a proportion of irradiated food would involve any nutritional hazard; the margin of safety that at present exists in the United Kingdom in the consumption of vitamins (nutrients that are specially vulnerable to destruction by radiation) is sufficient to cover the losses that might reasonably be expected to result from irradiation. Nevertheless the extent of loss of nutrients in a particular food or foodstuff to be expected from irradiation, together with cooking if subsequent cooking is to be expected, would have to be considered with respect to any proposal for the irradiation of it and special care would be needed in the consideration of any proposal relating to a food that might be an important vehicle of a particular nutrient to any special section of the community.

**The possible presence of toxic substances in irradiated food**

130. Most of the evidence concerning the wholesomeness of irradiated food has come from experiments in which animals have consumed the irradiated food for a long time. The results have been negative. Such irradiated food should contain all the possibly toxic substances that might provide a hazard for

man. Although a hundred-fold margin of safety cannot be realised in tests with irradiated food, in most instances some margin does exist. The results of the very extensive tests that have been carried out can lead only to a conclusion that irradiation under the conditions employed did not make the food toxic to the experimental animals so that no hazard to a human consumer is to be expected. Any proposal for the irradiation of food intended for human consumption ought nevertheless initially to be supported by evidence of a lack of toxicity to animals — acute and chronic — of the food which has been treated under the defined conditions.

131. Extensive tests on a wide range of foods, carried out particularly in the United States of America, have yielded no evidence for the formation of carcinogens on the irradiation of food. The Working Party considers that each proposal for the irradiation of food intended for human consumption be supported by information that is sufficient to allow the carcinogenic hazard to be assessed by the appropriate experts.

**The possible presence of chemical mutagens in irradiated food**

132. The evidence considered in paragraphs 64 to 66 is too exiguous to allow any final conclusion to be drawn about this important matter; the conclusion of the Working Party is that the existence of a hazard in this respect to the human consumer of irradiated food is most unlikely, but the possibility must be kept under review.

**The possible presence of induced radioactivity in food**

133. When food is treated with radiation of energy 10 MeV none of the common chemical elements of food is induced to become radioactive, although some elements which may be present in trace amount are susceptible to such a change under these conditions. The total radioactivity of most food irradiated at 10 MeV can be calculated to lie, 24 hours after irradiation, within the limits of the natural variation in the intrinsic raidoactivity of food, and the increase might well be too small to measure experimentally. No measurable increase in radioactivity has in fact been observed with food irradiated under such conditions. Nevertheless the induced radioactivity calculated to result from treatment with 10 MeV radiation is about one-hundred times that estimated to follow treatment with radiation of 5 MeV. The Working Party concluded that although the consumption of any food treated with 5 MeV radiation would involve no hazard, a similar assumption could not always be made with respect to food treated with radiation of energy greater than 5 MeV. The Working Party is therefore agreed that if any proposal is made for the treatment of food with radiation of energy greater than 5 MeV the possibility of hazard to the consumer from induced radioactivity in the food would need careful consideration in each specific instance.

134. Precautions must be taken to ensure that the containers used to hold food during irradiation contain no more than a trace, to be defined, of any element susceptible of being involved in the induction of radioactivity by radiation of the energy proposed for use.

**Possible microbiological hazards from the consumption of irradiated food**

135. In relation to sterilisation by irradiation the outstanding hazard of bacterial origin arises from the fact that *Cl. botulinum* toxin, and *Cl. botulinum* in spore form, are not readily susceptible to destruction by radiation, and that the spores

of this organism could remain viable in irradiated food under conditions in which all spoilage organisms had been destroyed. The safety of the methods employed in the canning industry is reinforced by the fact that some spoilage organisms are more resistant to destruction by heat than are the spores of *Cl. botulinum.* If therefore sterilisation by heat is not completely effective the organisms present are most likely to include some which cause spoilage of food, so that the food is almost certain to be rejected. But if irradiation designed to induce sterility is not completely effective the remaining organisms could consist wholly or largely of *Cl. botulinum.* Since food in which *Cl. botulinum* has produced its toxin is not necessarily thereby rendered so spoiled as to ensure its rejection, the destruction of spoilage organisms by irradiation under conditions in which some *Cl. botulinum* remained could provide a hazardous condition. It is true that the conditions under which *Cl. botulinum* can grow are restricted, that irradiated food remains uncooked and in some instances is iiable to autolysis unless cooked or stored at a cool temperature, and that thorough cooking destroys *Cl. botulinum* toxin. Although these factors together provide a substantial protection against the consumption of irradiated food containing *Cl. botulinum* toxin, this safeguard is not absolute (paragraph 114). There is no room for a margin of error in the operation of any process put forward for serious consideration as a replacement of sterilisation by heat in the industrial treatment of food.

136. As already stated, (paragraph 122), pasteurisation by irradiation could be safer than treatment by heat for the same purpose. But despite this, and despite the fact that certain foods which have in effect been heat-pasteurised are now sold without control apart from the general provisions of the Food and Drugs Acts (paragraph 8) there clearly exists a case for the control of pasteurisation by irradiation. This is so because certain foods which would not be pasteurised by heat may be pasteurised by irradiation, and new territories are likely to be entered in this way. Moreover radiation is a new process and can and should be controlled from the start according to scientific principles.

137. The temperature of storage of any food capable of causing food poisoning which had been pasteurised by irradiation would need to be rigorously controlled. The question of what, if any, warning should be included on the label ln relation to the need for storage in a cold place and for adequate cooking would be a matter for consideration in relation to each permitted use of irradiation.

138. Food may contain viruses and other related infective agents. Little is known of the effect irradiation would have in such circumstances (paragraphs 120 and 121). With increasing experience such matters should be reviewed.

**The principles on which the control of the irradiation of food should be based**

139. Although much of this Report has been devoted to a consideration of the hazards which might arise from the consumption of irradiated food, the Working Party concludes that the evidence for the wholesomeness of food which has been irradiated under specified and closely controlled conditions, is reassuring.

140. As has already been stated in paragraph 127 of the Report the Working Party considers that control is desirable. Such control should take the form of a prohibition from which exemption could be obtained under specified conditions. In paragraphs 13 and 14 the question was raised whether every food and food product, and every type of treatment, should be considered as a separate problem, or whether exemption could be considered for groups of

foods and food products and for ranges of treatment. The Working Party concludes that at first exemption should be confined to an individual food or foodstuff treated by radiation in a closely defined manner, and that an application for exemption should be associated with evidence of the wholesomeness of food which had been irradiated under the conditions proposed for industrial use. In time, and in the light of the experience gained in the operation of such control, it is most probable that a system could be developed by which groups of similar foods and food products, treated in similar ways, may be exempted. Experience will be needed in order to establish the principles on which foods and treatments may be grouped.

141. The introduction of prohibitive control, associated with the granting of exemption from it under appropriate conditions, necessitates the setting up of a scrutinising body. Recommendations as to the composition of such a body, its setting up, its terms of reference, and the mode of its functioning, are matters which the Working Party considers to be outside its terms of reference. It is clear however, that such a body ought to include experts versed in a wide range of disciplines.

142. The Working Party believes that applications for exemption will need to be considered in the light of evidence which includes that relating to the following points. Where appropriate, reference is given to some of the relevant paragraphs in the Report:—

(1) the source, energy and dose of ionising radiation to be used for the treatment of food (17–19, 88–93, 98);

(2) the precise nature of the food and the conditions under which it is to be irradiated, such as, e.g., temperature, presence or absence of oxygen (50);

(3) the nature of the containers in which the food is to be irradiated (48, 94) and subsequently stored (50, 115, 122);

(4) the minimum time after irradiation at which the food will be made available for human consumption (90);

(5) the proposed conditions of storage of the irradiated food (50, 114–116, 122); and the maximum period of storage proposed;

(6) the extent to which the nutrients in it are affected by the proposed irradiation. This will be of particular significance when the food in question is considered to contribute importantly to the nutrition either of the population of the country as a whole or of that of particular groups within it (67);

(7) the nature and results of tests for wholesomeness (71–75) carried out on food irradiated under the specified conditions, stored, and then cooked, if cooking be usual before the food in question is consumed. The tests should include investigations for the possible presence of toxic substances in general (68–70), and of carciongens (76–80) and of radioactive substances (81–94), in particular;

(8) the possibility of a microbiological hazard from the consumption of irradiated food, before and after storage under the stated conditions.

143. Although the Working Party's chief concern is with food intended for human consumption the irradiation of food intended for consumption by animals should not *ipso facto* be exempted from the provisions of the prohibiting control. Each case ought to be considered by a scrutinising body.

### Detection in food of previous treatment by radiation

144. The effective application of legislation which is intended to provide a means of regulating an industrial process is normally dependent upon a means of detecting a breach of the regulations. Any system of control which is designed to prohibit the irradiation of food intended for human consumption without specific exemption should normally be associated either with a control of the sources of irradiation or a means of detecting whether or not any sample of food had previously been irradiated. Information about the kind and amount of irradiation is also necessary. With these needs in mind detectable changes in irradiated food which are specifically attributable to radiation have been sought.

145. In this connection the evidence showed that the most sensitive instrument yet devised for "whole body counting" is less than one-hundredth the sensitivity required to detect, without chemical concentration, any radioactivity induced by irradiation of food with 5 Mrad of gamma-radiation from cobalt-60.

146. The chemical changes induced in food by its treatment with such radiation are also small and could not be attributed with certainty to the effects of irradiation. Nevertheless, the use of radiation in the food industry might be restricted to the treatment of only a limited number of foods, as seems possible from the indications at the present time. If this is so more extensive research on the effects of irradiation on these foods may reveal changes which can be used to indicate whether or not irradiation has taken place, and how much radiation has been applied. Indeed ultimately tests might be developed which will be comparable, in simplicity and ease of performance, with the phosphatase test for heat-pasteurised milk and the $\alpha$-amylase test for heat-pasteurised liquid egg.

147. Our survey of the evidence leads us to conclude that no detectable physical or chemical changes are known to occur in food as the result of irradiation which are attributable solely and exclusively to the action of the radiation. At the present no means is known to us which could be employed to determine from an examination of the food itself whether or not it had been treated with radiation of the sort and in the doses we are considering.

## CONCLUSION

148. As the result of their deliberations the Working Party agreed that the use of irradiation for the treatment of food intended for human consumption should be controlled and that the evidence for the safety of the products of such an application of radiation should be kept under review.

## RECOMMENDATIONS

149. (1) The irradiation of food and food products intended for human consumption be controlled.

(2) This control be achieved by means of prohibition with exemption to be granted under conditions to be specified.

(3) Initially, exemption be granted after consideration of an application therefor, which is supported by adequate evidence, in respect of an individual food product treated by radiation in a defined manner.

(4) After experience has been gained of such a procedure consideration be given to the granting of exemption, after examination of an application therefor supported by adequate evidence, for groups of similar foods and food products treated in similar ways.

(5) The evidence submitted in support of an application for exemption include that relating to the following matters: (a) the reasons for the proposed irradiation of the food intended for human consumption and the nature of any special group of consumers envisaged; (b) the source, energy and dose of the ionising radiation to be used for the treatment of the food; (c) the nature of the containers in which the food is to be irradiated and subsequently stored; (d) the proposed conditions and period of storage of the irradiated food; (e) the nature and results of tests for wholesomeness carried out on food irradiated under specified conditions, stored, and then cooked if cooking be usual before the food is consumed. The tests should include investigation for a possible diminution in nutritional value and for the possible presence of toxic substances in general and of carcinogens and of radioactive substances in particular; (f) the nature and results of microbiological tests on the irradiated food before and after storage under the stated conditions.

(6) The irradiation of food intended for consumption by animals be not *ipso facto* exempted from the provisions of the prohibiting control.

(7) A body be set up charged with scrutiny of applications for exemption from the prohibiting control, and with advice as to the conditions of their acceptance or rejection.

(8) The composition of the scrutinising body and its terms of reference be a matter for consideration if and when the other recommendations in the Working Party's Report have been accepted in principle.

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# GLOSSARY

*by*

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## Introduction

This glossary sets out to define some of the possibly esoteric terms used in those sections of the Report of the Working Party on the Irradiation of Food which are concerned with physics. The definitions in any dictionary are necessarily circular, and those in this glossary are no exception to this rule and the circles in it are relatively small. In the circumstances those whose knowledge of physics is meagre may need to read many definitions in order to understand one. Some words in the glossary do not occur in the Report but are useful or necessary for the definition of words that do appear there. In some instances, at least, the definitions are necessarily imprecise simplifications of more exact complexities but it is hoped that no serious inaccuracies exist in the definitions provided.

Where, in this glossary, a word is italicised thus — *nucleus*, the word in question is defined elsewhere in the glossary.

**Alpha particle.** The *nucleus* of a helium atom. This contains two *neutrons* and two *protons*. It therefore has two positive charges, so that its *Atomic Number* is 2. Its *Mass Number* is $2 + 2 = 4$. Alpha particles are in some instances ejected from the *nuclei* of heavy *radioactive nuclides* during *radioactive decay*.

**Atom.** An atom consists of an *atomic nucleus*, which carries a positive charge of electricity, and *orbital electrons* which can be regarded as revolving round the *nucleus* in *orbitals* grouped in *shells*. The *electrons* are attracted to the *nucleus* because they each carry a negative charge of electricity but can be regarded as maintaining their distance from the *nucleus* by virtue of a movement around it, like planets revolving around the sun. The total positive electric charge of the *nucleus* is ordinarily numerically equal to the total negative charge of all all the *orbital electrons*, so the atom as a whole is electrically neutral. The chemical identity of the atom is determined by the value of the total positive charge on the *nucleus* — the *Atomic Number*. Nearly all the mass of an atom is concentrated in the *nucleus*, and the *Mass Number*, which refers to the *atomic nucleus*, is very nearly numerically equal to the *Atomic Weight*, which refers to the atom as a whole.

**Atomic Nucleus.** The *nucleus* of the *atom* consists essentially entirely of *protons*, which carry a charge of positive electricity, and of *neutrons*, which carry no charge. The number of *protons* in the *nucleus*, and therefore the number of positive charges in it, is characteristic of the element — the *Atomic Number* — and is numerically equal to the total number of *orbital electrons* normally present in the *atom*. The mass of the atomic nucleus is characterised in terms of its *Mass Number*, which is numerically equal to the total number of *protons* together with the total number of *neutrons* in the *nucleus*. The suggestion has been made that the nuclear *protons* and *neutrons* can move within the *nucleus* rather like the *molecules* in a drop of liquid.

**Atomic Number.** The Atomic Number of an *atom* is numerically equal to the number of *protons* in the *nucleus* of the *atom*. The Atomic Number indicates the number of positive charges on the *nucleus* and the number of *orbital electrons* normally present in the *atom*, and determines the chemical identity

of the *atom.* In British usage the atomic number is usually indicated by a subscript number preceding the chemical symbol of the element in question. For example $^{12}_{6}C$ is the common non-radioactive *isotope* of carbon, of *Mass Number* 12 and *Atomic Number* 6.

**Atomic Weight.** The atomic weight of an element is the mean weight of the *atoms* present in it compared with that of an *atom* of oxygen, the latter being arbitrarily taken as 16. Since the atomic weight of hydrogen is approximately one the atomic weight of an element is approximately numerically equal to the weighted mean of the *Mass Numbers* of its *isotopes.*

**Beta particle.** During the *radioactive decay* of many *radioactive nuclides* electrons are ejected from the *atomic nucleus.* These *electrons* were described as beta particles before their identity as *electrons* had been established.

**Bremsstrahlung.** (German "braking radiation"). When fast *electrons* impinging on matter are deflected by the *atoms* of the matter, they may lose energy which can appear as *electromagnetic radiation* of a wide and almost continuous range of energies, which is known as *Bremsstrahlung. X-radiation* is *Bremsstrahlung* produced by the impinging of fast *electrons* on a suitable target, especially one of heavy metal.

**Chemical bond.** When *orbital electrons* of one *atom* enter an *orbital* or *orbitals* of another *atom*, and continue to move in a new path which may involve movement around the second *nucleus* only, or around both, a chemical bond may exist between two *atoms.* Often, though not always, two or more *electrons* are involved in the formation of a *chemical bond*, one at least from every *atom* involved. In a highly simplified example, two *atoms* A and B can be considered, in each of which a single *unpaired electron* can become available for bond formation. A chemical bond can be formed if the *unpaired electron* from *atom* A, instead of moving alone in an *orbital* around the *nucleus* of this *atom*, traverses a path which takes it around *nucleus* A as before but now also around B in the same *orbital* as is occupied by the unpaired *orbital electron* in *atom* B. Simultaneously the previously unpaired *electron* from *atom* B will pursue a path around *nucleus* A as well as around *nucleus* B, spinning at all times in a direction opposite to that of the *electron* originally in *atom* A. In this way both *electrons* pursue a pathway around both *atomic nuclei*, the two *electrons* spinning in opposite directions in the same double *orbital.* The *molecule* formed by the formation of a chemical bond of this sort is, as a whole, electrically neutral.

**Curie.** A unit of *radioactivity.* A curie was originally defined as the number of *nuclear disintegrations* which occur each second in one gramme of radium. It is now defined as that amount of radioactivity which involves the *disintegration* of $3{\cdot}7 \times 10^{10}$ *atomic nuclei* in a second.

**Deuterium.** An *isotope* of hydrogen, with *Atomic Number* 1 and *Mass Number* 2. Deuterium is sometimes known as "heavy hydrogen" since the bulk of ordinary hydrogen consists of an *isotope* of *Atomic Number* 1 and *Mass Number* 1.

**Disintegration.** Disintegration is the term used to describe the spontaneous supture of the *atomic nucleus* of a *radioactive nuclide.* The products of disintegration frequently consist of *beta particles* (*electrons*), *gamma-radiation*, *alpha particles* and a new slightly lighter *nucleus.* They differ from the products of *nuclear fission*, induced by the collision of, for example, a *neutron*

with the *nucleus* of a suitable *radioactive nuclide*. In such induced *fission* the products of the break up of the *nucleus* can include the nuclei of much lighter *nuclides* as well as smaller *nuclear particles*.

**Dyne.** A unit of force. It is the force required to increase in one second the speed of a moving mass of one gramme weight by one centimetre per second.

**Electromagnetic radiation.** Electromagnetic radiation describes a means whereby energy may be transmitted through empty space. For mathematical treatment it can be regarded as having the form of waves. Gamma-radiation, which has a very short wavelength ($10^{-10}$ — $10^{-8}$ cm), soft X-radiation with a longer one ($10^{-8}$ — $10^{-7}$ cm), ultraviolet light ($10^{-7}$ — $4 \times 10^{-5}$ cm), visible light ($4 \times 10^{-5}$ — $7 \times 10^{-5}$ cm), infra-red radiation ($7 \times 10^{-5}$ — $10^{-1}$ cm) and radiowaves ($10^{-1}$ — $10^{6}$ cm) are all forms of electromagnetic radiation. Energy can be released from, or projected into, electro-magnetic radiation only in discrete amounts called *photons*. The greater the wavelength, the smaller the value of the *photons* and with electromagnetic-radiation of wavelength about that of very short radio waves and longer the *photon* is so small that it imposes no appreciable limitation on the transfer of energy to or from electromagnetic radiation.

**Electron.** A fundamental particle of matter possessing a negative electric charge. The electron possesses about 0·05 per cent of the weight of a hydrogen atom, and its charge is equal to about $4{\cdot}77 \times 10^{-10}$ *electrostatic units*. Electrons exist in *atoms*, where they occupy *shells* around the *nucleus*. They also occur free, and an electric current in matter is a movement of electrons in it. They are often (though not always) one of the products of the *radioactive decay* of *radioactive nuclides* in which case they are known as *beta particles*, a name given before their identity as electrons ejected from an *atomic nucleus* was known. They almost certainly do not exist as such in an *atomic* nucleus but are formed, during *radioactive decay*, by the transformation of a *neutron* into an electron and a *proton*, the electron being ejected from the *atomic nucleus* and the *proton* being retained.

**Electron shell.** A group of *orbitals* containing electrons of somewhat similar energy, and therefore of similar average distance from the *atomic nucleus*. Electron shells containing two, eight, and eighteen *electrons* are found in many *atoms*.

**Electron volt.** A unit of energy. An *electron* moving under the influence of the electric field which results from a difference of one volt, acquires an energy of one electron-volt. One electron volt $= 1{\cdot}6 \times 10^{-12}$ *ergs*.

**Electrostatic unit.** A unit of electric charge. Two charges of like sign each of one electrostatic unit one centimetre apart in a vacuum repel one another with a force of one *dyne*.

**Erg.** A unit of energy. An erg of energy results from the action of a *dyne* of force over a distance of one centimetre. A mass of two grammes weight moving with a speed of 1 cm/sec. has an energy of 1 erg. One calorie of heat is equivalent to $4{\cdot}2 \times 10^{7}$ ergs of energy.

**Excitation.** See "excited state".

**Excited State:**

(a) *Atomic nucleus.* If the *nucleus* of an *atom* absorbs energy, for example, from *gamma-radiation*, it is said to become excited. As a result its constituent *neutrons* and *protons* may be thought to move faster within the *nucleus*. If

the *nucleus* is sufficiently excited a *nuclear* particle may escape from it and some of the excess energy of the *nucleus* thus be lost. If a *neutron* is emitted the *nucleus* continues to possess the same charge but it loses mass, with a consequent reduction in its *Mass Number;* it thus becomes the *nucleus* of an *isotope* of the original *atom*. If it loses a *proton*, or other charged particle, it alters its charge and therefore its *Atomic Number* changes and so it becomes the *nucleus* of a different element. In some instances an excited nucleus may remain for some time in a *metastable* state without losing a *nuclear particle.* It may subsequently lose its extra energy solely by the emission of *gamma-radiation.*

(b) *Orbital electrons.* If an *orbital electron* absorbs energy it moves into another *orbital* farther from the *atomic nucleus*, and one that is characteristic of the higher amount of energy that the *electron* now possesses. When one or more of its *orbital electrons* have absorbed energy and have thus been induced to enter *orbitals* of higher characteristic energy, the *atom* (more exactly its extra-nuclear portion) is said to be in an excited state. If the energy imparted to an *orbital electron* is sufficient for the *electron* to escape entirely from the attraction of the positive *nucleus* and to move off as a free electron, the excited *atom* becomes a positively charged *ion*. Sometimes a fast moving free *electron* can excite an *atom* by moving into the attractive positive field of its *atomic nucleus* and, by entering an *electron shell*, convert the neutral *atom* into a negatively charged *ion*.

(c) *Excited atom.* An *atom* can be excited by absorbing energy in such a way that excitation occurs (i) in the *nucleus*, (ii) in the *orbital electrons*. Both states can occur simultaneously. Excitation of the *orbital electrons* may result in the loss of an electron with the production of a positively charged *ion*.

(d) *Excited molecule.* If one of the constituent *atoms* of a *molecule* becomes excited the excitation is liable to spread throughout the *atoms* of the *molecule*, and the *molecule* itself is said to be excited. If the excitation of the *molecule* is sufficient the rupture of *chemical bonds* can occur with the formation of *free radicals*.

**Fission.** The splitting of the *nucleus* of an *atom*, usually one of high *Mass Number*, into a number of parts of roughly similar *Mass Numbers* together with *nuclear particles*. Fission usually results from the entry into the *nucleus* of a moving particle, nearly always a *neutron*. Fission causes the release of much energy in the form of heat and of *gamma-radiation*.

**Free Radical.** A free radical is a *radical* in which one or more *unpaired electrons* are present, and which is therefore highly chemically reactive. Because it is so chemically reactive a free radical exists under normal conditions for only a very short time, perhaps a few microseconds. It usually disappears by taking part in a chemical reaction in such a way that its unpaired electron (or electrons) becomes paired. As a result of receiving energy from *ionising radiation* a molecule of water can become so *excited* that a *chemical bond* is split, with the formation of a hydrogen *atom* (H), which is electrically neutral and which is a *free radical*, and an OH(free) radical, which also is uncharged. Any *ion*, formed under the influence of *ionising radiation*, is necessarily in an *excited state;* whether or not it is a *free radical* depends on its possession, or lack, of one or more *unpaired electrons*. A positively charged *ion*, formed under the influence of the action of *ionising radiation* on a *molecule*, may capture an *electron* and by thus neutralising its overall electric charge, can

remain in an *excited state.* The *excited state* may be such that *chemical bonds* split with the formation of two or more uncharged *free radicals.* Alternatively, the *excited state* directly induced by absorption of energy from the *ionising radiation* may be sufficient to cause the splitting of *chemical bonds* and the formation of *free radicals.* An *excited ion* may split to give one *ion* and one uncharged *free radical*, and there are many other possible ways in which *free radicals* may ultimately appear as the result of the influence of *ionising radiation* on *molecules* and *ions.*

**Gamma-radiation.** Gamma-radiation consists of *electromagnetic radiation* of a number of very short and sharply defined wavelengths, usually one or two in number, produced by the spontaneous *disintegration* of the *atomic nucleus* of certain *radioactive* substances. It may also be released from an *atomic nucleus* which is induced by any cause to undergo *fission*, and by a *metastable atomic nucleus.*

**Half-life.** In application to *radioactive decay*, the term half-life means the period during which one-half of the *atoms* of any given amount of a *radioactive nuclide* will be expected to undergo *radioactive disintegration.* The half-life of a *radioactive* element is independent of its state of chemical combination and of physical and chemical conditions in general.

**Ion.** An ion is an *atom*, *molecule*, or fragment of a *molecule*, that has acquired a positive or a negative electric charge. If the number of *orbital electrons* in the *ion* is such that a chemically stable state exists, an *ion* may exist indefinitely, particularly in solution. In a gas, positively and negatively charged *ions* usually mutually neutralise unless they are removed from each other's influence. Ions are sometimes also *free radicals.*

**Ionising radiation.** If the interaction of radiation and matter results in the formation of *ions* in the matter, the radiation is described as ionising radiation. The term covers *electromagnetic radiation* of very short wavelength (*gamma-radiation* and *X-radiation*), fast moving charged particles such as *electrons*, *protons* and *alpha* particles, and fast moving uncharged particles, such as *neutrons.* In the Report the unqualified term "ionising radiation" means only *gamma-radiation*, *X-radiation* and fast moving *electrons.*

**Isomer.** See *isomer activation* and *isomeric nuclei.*

**Isomer activation.** The conversion of an *atomic nucleus* into a state possessing higher energy is described as isomer activation. In the higher state of energy the *atomic nucleus* is *metastable* and gradually the additional energy is lost.

**Isomeric nuclei.** Isomeric *atomic nuclei* are *atomic nuclei* of the same *nuclide* which are in different states of *excitation*, and which therefore possess different amounts of energy.

**Isotope.** Two *nuclides* which have the same *Atomic Number* but different *Mass Numbers*, are isotopes of one another. Isotopes have the same chemical properties but differ in some physical properties. The naturally occurring elements are usually mixtures of two or more isotopes. Many *radioactive* isotopes of naturally occurring stable elements have been artificially produced by bombarding *atomic nuclei* with *nuclear particles*, especially with *neutrons.*

**Kilo-.** A prefix meaning a thousand (times).

**Mass Number.** The sum of the number of the *protons* and the *neutrons* in an *atomic nucleus* is the Mass Number of the *nucleus.* The Mass Number is

numerically approximately equal to the *Atomic Weight* of the *nuclide* concerned. In British usage the Mass Number of a *nuclide* is indicated either by a superscript number preceding the chemical symbol for the element, e.g. $^{14}C$ (radioactive carbon), or by a number which is suffixed to the name of the element, e.g. cobalt-60 (radioactive cobalt).

**Mega-.** A prefix meaning a million (times).

**Metastable.** A metastable *atomic nucleus* is one which possesses energy which is above that normally possessed by *nuclei* of the *nuclide* in question. The energy is usually released in the form of *gamma-radiation*, the rate of release being characteristic of the particular metastable state of the *nuclide* in question. A metastable state of a *nuclide* is generally indicated by a suffix letter "m" after the *Atomic Number*. Thus "tin-117m" indicates the metastable condition of the *isotope* of tin which has a *Mass Number* of 117.

**Micro-.** A prefix meaning one-millionth (of).

**Milli-.** A prefix meaning one-thousandth (of).

**Molecule.** A molecule is formed when *atoms* are joined together by the formation of a *chemical bond* or bonds between them. If the *atoms* of an element possess *unpaired electrons* they will usually, though not always, join up with *atoms* of their own kind to form molecules, with *pairing* of the previously *unpaired electrons*.

**Neutron.** A fundamental particle with no electrical charge and a *Mass Number* of 1. The mass of a *neutron* is approximately equal to that of a *proton*. An *atomic nucleus* contains neutrons which in rare instances are ejected during the *radioactive decay* of *radioactive nuclides*. More frequently *radioactive decay* is associated with the apparent conversion of a nuclear neutron to an *electron*, which is ejected, and a *proton*, which remains in the *nucleus*. The entry into an *atomic nucleus* of a neutron from any external source changes the *Mass Number* but not the *Atomic Number* of the *nuclide*, and therefore produces an *isotope* of the original element, which may or may not be *radioactive* (see *neutron activation*).

**Neutron activation.** Since a *neutron* is uncharged it can move close to an *atomic nucleus* without suffering electrical repulsion either by the negative charges on the *orbital electrons* or by the positive charge on the *nucleus*. A *neutron* of appropriate kinetic energy can enter an *atomic nucleus* and so excite it that the *nucleus* ruptures, either immediately or after an interval. The *fission* or *disintegration* of an *atomic nucleus* so induced is described as resulting from neutron activation of the *nucleus*. Neutron activation of an *atomic nucleus* may therefore induce either immediate *fission*, or result in the formation of a *radioactive nuclide* which, after an interval, may emit *nuclear particles* and *gamma-radiation*.

**Nuclear particle.** The particles that may be spontaneously ejected by the nucleus of a *radioactive nuclide* during *radioactive decay*, or may be released during *nuclear fission* induced by any means. Nuclear particles include *alpha particles*, *electrons*, *neutrons*, *positrons* and *protons*.

**Nucleus.** See "Atomic nucleus".

**Nuclide.** Any single species of *atom* characterised by a specific *Atomic Number* and a specific *Mass Number* is now usually termed a nuclide, a term which is almost, but not exactly, equivalent to *isotope*. An *isotope* is strictly, by its definition, one of a number of *isotopes*. For example, *deuterium* is an isotope

of hydrogen but it is in itself a nuclide of *Atomic Number* 1 and *Mass Number* 2. An element usually consists of a mixture of *isotopes* which are nuclides with the same *Atomic Number* (and therefore with the same chemical properties), but with different *Mass Numbers* and therefore different *Atomic Weights*.

**Orbital.** An orbital may be considered as the pathway pursued by an *electron* in an *atom* around the *atomic nucleus*. Groups of orbitals containing *electrons* of somewhat similar energy, and therefore of similar average distance from the *nucleus*, are known as *electron shells*. Most electrons in orbitals are *paired*, that is there are two *electrons* in each orbital, spinning in opposite directions.

**Orbital electrons.** In an *atom* the orbital electrons occupy *shells* around the *nucleus* within which they may be regarded as moving in *orbitals*, which are comparable with the orbits in which planets move around the sun. The precise *orbitals* occupied vary according to the state of excitement of the *atom*, and to its chemical combination. When one or more *electrons* from one *atom* occupy an *orbital* which partly lies within the sphere of attraction of the *nucleus* of another atom, a *chemical bond* may exist between the two atoms, and they may then form part of a *molecule*.

**Paired.** See "paired electrons".

**Paired electrons.** Two *electrons* in one *orbital*, spinning in opposite directions.

**Photon.** A photon is the smallest amount of energy that can be transferred from *electromagnetic radiation* to *atoms* (and therefore to *molecules*), which can thus be induced to enter an *excited state*. Energy can be transferred from *electromagnetic radiation* to matter (*atoms and molecules*), and conversely, only in integral numbers of photons. The energy value of the photon is not fixed but is related by a simple equation to the wavelength of the radiation. The shorter the wavelength the bigger the value of the photon.

**Positron.** A fundamental particle with a mass the same as that of an *electron* and a positive electric charge numerically equal to the negative charge of an *electron*. Positrons are sometimes ejected by the *atomic nuclei* of *radioactive nuclides* during *radioactive decay*.

**Proton.** The nucleus of a hydrogen atom. Since it has one positive charge its *Atomic Number* is 1. Its *Mass Number* is also 1. Any *atomic nucleus* contains protons equal in number to the positive charge carried by it. A positively charged hydrogen *ion* is a proton. Protons are in rare instances ejected from the *nucleus* of a *radioactive nuclide* during *radioactive decay*.

**Rad.** A unit for the measurement of the energy absorbed from *ionising radiation* by the matter through which the radiation passes. Quantitatively a dose of one rad involves the liberation of 100 *ergs* of energy into each gramme of matter through which the radiation passes.

**Radical.** A group of *atoms*, joined by *chemical bonds*, which constitutes part of a *molecule*. If the *chemical bond* joining the radical to the rest of the *molecule* is broken, for example by ionising radiation, a *free radical* may result.

**Radioactive.** A *nuclide* is said to be radioactive when the *nuclei* of its *atoms* undergo spontaneous *disintegration* with the release of one or more *nuclear particles*, together with, usually, *gamma-radiation*. It is also described as radioactive when its *atomic nuclei* are in a *metastable* state from which they can return to a normal condition by the release of energy, usually in the form of *gamma-radiation*.

**Radioactive decay.** The *atomic nuclei* of some *nuclides* can spontaneously *disintegrate* with the release of one or more *nuclear particles* together with, usually, *gamma-radiation.* The *atomic nucleus* left is usually that of a different element and if this is *radioactive* it will itself undergo radioactive decay. The process will be repeated until a stable *atomic nucleus* is formed, after which no further radioactive decay occurs. The proportion of the *nuclei* of a given *radioactive nuclide* which undergo spontaneous *disintegration* in a given time is constant and is unaffected by the physical or chemical state of the *atom.*

**Röntgen.** A unit for the measurement of the amount of radiation applied to matter. The application of approximately 1·07 röntgen of *X-radiation* or of *gamma-radiation* to food results in the absorption of one *rad*, or 100 *erg* of energy in each gramme.

**Shell.** See "electron shell".

**Tritium.** An isotope of hydrogen with *Atomic Number* 1 and *Mass Number* 3. Tritium is radioactive. Ordinary hydrogen consists mainly of an isotope of *Atomic Number* 1 and *Mass Number* 1.

**Unpaired.** See "unpaired electron".

**Unpaired electron.** An *orbital electron* alone in an *orbital.*

**X-Radiation.** Electromagnetic radiation of a wide variety of short wavelengths usually obtained from a machine designed for the purpose.

# APPENDIX I

*The Production and Properties of Gamma-Radiation and of High Speed Electrons and their Use in the Treatment of Food*

By F. G. Young

1. By definition ionising radiations are those which produce ions in matter. An ion is an atom, molecule or fragment of a molecule, which has acquired a positive or a negative charge.

2. The three types of ionising radiation with which the Report is concerned are X-radiation, gamma-radiation and fast moving electrons (paragraph 16 of the Report*) and in paragraph 19* it is stated that "Fast electrons have much less penetrating power than X-radiation or gamma-radiation of the same energy but, in other respects, under the conditions of irradiation considered in this Report, treatment of food with fast electrons can be regarded as equivalent to treatment with a similar dose of X-radiation or gamma-radiation except with respect to the possible induction of radioactivity (see paragraph 27)". The relevant evidence is set out in this Appendix, together with a discussion of the methods of providing suitable sources of these types of ionising radiation, the means of their employment for the treatment of food, and the means of measuring the radiant energy absorbed.

3. The conditions of irradiation considered in the Report are mainly the use of radiation with energy of 5 MeV or less in a dose of 6 Mrad or less (paragraph 44).

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* Unless otherwise indicated all references to numbered paragraphs refer to those in the main Report.

## Gamma-Radiation

4. Gamma-radiation can be regarded as electromagnetic waves of a wavelength much shorter than that of light, from which energy can be imparted to matter. It acts in the form of separate units of energy called photons. The energy value of the photon and the penetrating power of the radiation both increase as the wavelength of the electromagnetic radiation diminishes. The energy value of the photon, which is the characteristic energy of the electromagnetic radiation, is expressed in terms of electron-volts, the electron-volt being the energy change when an electron is accelerated under the influence of a potential difference of one volt (paragraph 20).

5. Since gamma-radiation does not carry with it an electric charge it is not deflected or repelled by the electric charges within atoms and therefore has greater penetrating power than charged particles, for example electrons, of similar energy. The relatively great penetrating power of gamma-radiation is illustrated by the fact that to reduce a given amount of gamma-radiation of 1·33 MeV to one half, passage through about 30 cm. of water is needed, whereas passage through only 0·3 cm. of water will reduce high-speed electrons of the same energy to the same extent.

6. When gamma-radiation interacts with atoms, energy may be transferred either to the nucleus or to the orbital electrons, or to both. The transfer of energy from the gamma-radiation to orbital electrons often results in the ejection of one of them (occasionally more) from the atom, the latter then becoming a positive ion (paragraph 29). Some of the ejected electrons may themselves eject orbital electrons from other atoms or they may enter the orbital electron shells of other atoms and, coming within the attractive influence of the positive field of the atomic nucleus, may temporarily remain to form a negatively charged ion (paragraph 29). The outcome is the formation of equal numbers of positive and negative ions (the charges of which ultimately neutralise each other) together with some electrically neutral but chemically reactive free radicals (paragraph 30). Many other intermediary reactions of a more complicated nature can occur but this simplified account is correct in outline.

## High Speed Electrons

7. When high speed electrons impinge on matter, orbital electrons in the atoms of the matter are usually ejected and changes similar to those described in paragraph (6) above are then initiated. In this respect therefore the actions on matter of gamma-radiation and of high speed electrons are similar, namely the appearance of equal numbers of positive and negative ions and of highly chemically reactive radicals (free radicals).

8. Unlike that of gamma-radiation the energy of fast electrons is rapidly transferred to the atoms on which they impinge, and for this reason their power of penetrating into matter is substantially less than that of gamma radiation of similar energy. The fact that fast electrons are deflected or repelled by the charges on orbital electrons of the atoms of the matter into which they pentrate is the chief cause of their rapid loss of energy.

9. Although a fast electron of energy of 5 MeV or less is unlikely to reach the nucleus of an atom on which it impinges it sometimes can get near enough for the direction of its path to be altered by the nuclear charge. Under such conditions, and also, to a minor extent when fast electrons are deflected or repelled by orbital electrons, the resulting change of velocity of the incident electron

results in the emission of electromagnetic radiation known as *Bremsstrahlung* (German "braking radiation"). The emitted electromagnetic radiation is of a wide and almost continuous range of energies, up to the energy of the incident electrons. This accounts for the almost continuous spectrum of the electromagnetic radiation emitted by X-ray tubes (see paragraph 17 below). *Bremsstrahlung* acts on atoms in the same way as gamma-radiation and its generation does not fundamentally alter the action of fast electrons on matter. It is largely or entirely through the production of *Bremsstrahlung* that fast electrons are able to cause those changes in the atomic nucleus that result in induced radioactivity (see paragraphs 27 and 28). Fast electrons of a given energy induce much less radioactivity in matter than X-radiation or gamma-radiation of the same energy (see paragraphs 27, 28 and 88) because of the necessary intermediate formation of *Bremsstrahlung* which are scattered away from, as well as towards, the atomic nucleus.

### Isotope Sources of Gamma-Radiation

10. When the atomic nuclei of radioactive substances undergo spontaneous disintegration the matter and energy released can appear in a number of forms, some of which are indicated as follows: (i) *gamma-radiation*, the nature of which has been discussed in paragraph (4) above; (ii) *beta particles*, which are electrons; (iii) *positrons*, which are particles of the same mass as electrons but with a single positive charge in place of the single negative one carried by an electron; (iv) *alpha particles*, which are more commonly ejected by heavier radioactive nuclei than by lighter ones. An alpha particle is the nucleus of a helium atom, carrying a double positive charge; (v) in a few instances the disintegration of the nucleus of a radioactive atom involves the ejection of a *proton*, which is the nucleus of a hydrogen atom and carries a single positive charge; (vi) in a very few instances the nuclear disintegration of a radioactive atom involves the ejection of a *neutron*. A neutron has the mass of a hydrogen nucleus but no charge.

11. For reasons of the sort discussed in paragraph (5) above, charged particles, unless they are extremely fast, have relatively low power of penetration into matter and are therefore stopped by filters through which gamma-radiation and neutrons can pass. Although neutrons are ejected during the disintegration of relatively few radioactive nuclei they are of importance since such ejected neutrons can convert stable nuclei into radioactive ones.

12. For the treatment of food, artificially prepared radioactive isotopes of cobalt and caesium have been used as sources of gamma-radiation, while so called 'spent fuel rods' have also been employed experimentally for this purpose.

13. **Cobalt-60** — Cobalt-60 is a radioactive isotope of cobalt, prepared artificially by bombarding natural cobalt (cobalt-59) with neutrons in a suitable nuclear reactor. It can easily be produced in relatively large amounts, and has moderately prolonged activity, the half-life being 5·3 years. Cobalt-60 emits gamma-radiation of two energies, 1·17 MeV and 1·33 MeV respectively and beta particles with a maximum energy of 0·31 MeV. The beta particles are easily absorbed, the quantity being reduced to one-half its initial value by passage through less than 0·01 cm. of water. The cobalt-60 is sealed in inner and outer stainless-steel tubes, which completely absorb the beta particles The amount of the gamma-radiation is reduced to one-half of its initial value by passage through about 30 cm. of water and very little of it is absorbed by the steel tubes

in which the cobalt-60 is housed. Because the half-life of cobalt-60 is 5·3 years its radioactivity diminishes by about 1 per cent each month and therefore the radioactive material must be replaced at suitable intervals.

14. For the irradiation of food or other materials the steel tubes containing cobalt-60 are usually fixed in parallel in a frame, the total amount of radioactivity being say 100,000 curies. The frame is housed in a chamber with concrete walls 5 feet thick, and across both sides of the frame are slowly passed the containers of the materials to be irradiated, the speed being determined by the strength of the source and the dose of radiation to be given. Usually the dose is administered over two equal periods, the containers being rotated between the half doses in order to obtain uniform treatment. The rate at which energy can be liberated into the irradiated material depends on the activity of the source and in practice is always likely to be less than a million rads an hour. This is much less than can be obtained from machine sources by means of fast electrons (see paragraph 19 below).

15. **Caesium-137.** Caesium-137 is a radioactive isotope of caesium which is obtained as a fission product of uranium and other elements in a nuclear reactor. Caesium-137 emits gamma-radiation with energy of 0·66 MeV and beta particles of energy 0·52 MeV and 1·2 MeV respectively, those with 0·52 MeV being more than eleven times as common as those of energy 1·2 MeV. It is not easy to isolate caesium-137 from the complex fission products obtained from a nuclear reactor, and this materials has not yet been prepared in an amount sufficient for the industrial treatment of food. Its production will need to be much cheaper per curie than that of cobalt-60 before its use for the treatment of food is likely to be developed industrially. If it does come into use for this purpose the means of applying the gamma-radiation to food are likely to be similar to those already adopted for cobalt-60.

16. **Spent Fuel Rods.** 'Spent fuel rods' are rods of uranium or other nuclear fuel in which different radioactive substances have been formed as the result of the operation of an atomic reactor. When the rods are first withdrawn from the reactor the spent fuel produces much gamma-radiation of many different energies, but because many of the radioactive isotopes present have short lives the amount of emitted gamma-radiation rapidly falls. The emitted radiation also contains charged particles and some neutrons are present, which have been produced by the interaction of gamma-radiation of energy of 1·66 — 2·2 MeV or more, with deuterium and any beryllium present (see paragraph 83). Furthermore a few of the short-lived radioactive products of the nuclear reactor, for example bromine-87 and bromine-89 with half-lives of less than one minute, themselves emit neutrons. The amount of induced radioactivity in food treated with the radiation from spent fuel rods is likely to be less than that induced by treatment with 5 MeV electrons, but other problems have to be considered with respect to the possible large-scale use of spent fuel rods for the treatment of food. Because their radioactivity is short lived the rods would have to be frequently replaced. For this reason a plant which used spent fuel rods probably could be operated only close to a nuclear reactor. It is unlikely therefore that spent fuel rods will be used for the industrial irradiation of food.

**Other possible sources of ionising electromagnetic radiation**

17. X-radiation and gamma-radiation are distinguished by convention as being produced respectively by non-nuclear and by nuclear reactions, but both are similar forms of electromagnetic radiation. X-radiation has a wide range of

energies, the average energy generally being lower than that of gamma-radiation. Gamma-radiation, on the other hand, is usually produced, during radioactive decay, in a limited number of sharply defined energy values. X-radiation is produced by the impinging of fast electrons on a target, especially one of heavy metal. In machines of conventional design only a small proportion of the energy in the impinging electron beam appears as X-radiation. The efficiency of conversion of the energy of fast electrons to that of X-radiation tends to rise as the energy of the radiation increases. The use of X-radiation as such for the treatment of food is unlikely to be proposed unless machines for its production are rendered more efficient or cheaper. But the principles involved in the use of X-radiation for the treatment of food would not differ from those set out in this Report.

**Machine sources of High Speed Electrons**

18. Free electrons from a heated cathode (a heated negative electrode) in an evacuated chamber are accelerated towards one or more anodes (positive electrodes) by an electric field. These moving electrons — a "cathode ray" — are focused into a beam by the imposition either of another electric field, or of a magnetic field, or of both, and the resultant beam is so directed that it does not impinge on the anodes but passes out of the chamber through a very thin metal window usually of aluminium or titanium. If a suitably varying magnetic field is applied to the beam of high speed electrons it can be made to sweep systematically over a large area. Although the electron-beam itself is not highly penetrating (see paragraph 8 above) penetrating X-radiation (*Bremsstrahlung*) is formed when it strikes matter and for this reason the machines which provide electron beams of high energy are usually housed within heavy concrete walls.

19. In the treatment of food the material is scanned by the electron beam until the required dose has been received. Millions of rads can be applied each second, which is a rate of application immensely greater than can be achieved with cobalt-60 as a source of gamma-radiation (see paragraph 14 above) but the limited power of penetration of an electron beam means that reasonable uniformity of treatment is not achieved if, for example, 5 MeV electrons are applied to material of the density of water in a thickness of more than about 1·7 cm. If treatment is applied from opposite sides, the total thickness over which uniformity can be achieved is about 3·4 cm.

20. Many different types of machine sources of high speed electrons have been produced, and much improvement in their design and efficiency has been effected during the past few years. Improvement can be expected to continue as time goes on. In some of the modern forms of machine source of fast electrons, the acceleration is achieved by short pulses of electrical energy and the beam of electrons is therefore interrupted. This is no great disadvantage in the treatment of food by radiation. Machines are liable to vary somewhat with respect to the energy of the electron beam and the rate of delivery of the radiation energy. Such changes are necessarily to values below those intended and never to those above, and such variations are therefore unlikely to subject food to radiation energy above that set as the upper limit. But such possible variations underline the need to record continuously the dosage delivered by machine sources to food under treatment.

**The Dosimetry of Radiation in the Treatment of Food**

21. As was pointed out in paragraph 22 of the Report the rad is a unit based on the energy absorbed from the radiation by the irradiated material, and is not a measure of the radiation applied to matter since not all of the radiant energy is absorbed. An instrument or material for measuring the amount of radiation energy actually released within the food under treatment must therefore be available when a given dose of radiation is to be applied. Food under treatment is usually treated first from one side and then from the other because of the attenuation of the beam in matter. With a long-lived isotope source, such as cobalt-60, the assumption can reasonably be made that the rate of absorption of energy at a fixed point remains constant over the entire period of irradiation, but such an assumption could not be made for a machine source.

22. Usually the amount of energy absorbed is expressed as rads, one rad being 100 ergs of absorbed energy in each gramme of irradiated matter (paragraph 22). A fundamental method of measuring the absorbed energy is calorimetry. The radiation is absorbed by a suitable calorimeter and the heat received is measured by any appropriate method. Secondary means of measuring the absorption of ionising radiation include the use of radiation-sensitive chemical reactions, such as the oxidation of ferrous to ferric ions, or the reduction of ceric to cerous ions, under suitable conditions. Such methods can be standardised by calorimetric means. Another secondary means is through the colour changes that occur under the influence of ionising radiation in some coloured substances, such as certain coloured glasses and synthetic plastic materials. The changes in such coloured materials must continually be standardised, but are likely to provide the most conveniently simple method for routine use.

23. The problems of dosimetry in the treatment of objects of irregular shape, such as a sheep carcase, are not simple but are soluble within certain limits. With objects of such thickness fast electrons cannot be used. The assumption which is borne out by experiment, can be made that a model of the object in a suitable container filled with water will give, with gamma-radiation, a pattern of distribution of dose similar to that to be expected within the meat itself. With such a "phantom" the dose actually received in various sites in the interior of the object can be directly measured by the introduction of assay material. Inspection of the results will indicate the total dose throughout the whole object when the radiation is applied for a given time. Calculation easily indicates the time needed for application of the required dose. With such an irregular object the ratio of the biggest dose applied in any part to the smallest dose applied in any part might be as large as 1·5/1 if the maximum thickness were 8–9 inches and the density equal to that of water. That is to say some part of the object might receive a dose of radiation 50 per cent greater than another. With objects sufficiently thin to be treated by fast electrons the solution to the problem of dosimetry does not differ in principle from that with gamma-radiation.

# APPENDIX II

*Radioactivity induced in food by treatment with gamma-radiation from cobalt-60 or with X-radiation or fast electrons*

Tables 4 and 5 are extracted with the author's permission from a publication with the title "Activity induced in food by electron, X-ray and cobalt-60 gamma irradiation" published by the Atomic Energy Research Establishment [275].

Table 4 expresses the maximum radioactivity which might be induced in food by radiation of different energies as a proportion of the maximum permissible concentration of the radioactivity in question in drinking water. The calculations assume that the nuclides in which activity is induced are present in food in the maximum amounts which are credible. Table 5 expresses (as a proportion of the maximum permissible concentration in water) the radioactivity induced by 6 Mrad of radiation of different energies, in certain foods in which the actual concentrations of the relevant nuclides have been assessed.

### TABLE 4

*Calculated maximum radioactivity induced in food by radiation of different energies if the susceptible elements are assumed to be present in food in the maximum amounts which are credible.*

(Note: The radioactivity is expressed as a proportion of the maximum permissible concentration in drinking water).

| *Time* | *Cobalt-60* | *5 MeV* *Elect.* *X-ray* | *7 MeV* *Elect.* *X-ray* | *10 MeV* *Elect.* *X-ray* | *15 MeV* *Elect.* *X-ray* |
|---|---|---|---|---|---|
| Initial | $2\cdot10^{-4}$<br>Ba, Sr, Y | $2\cdot10^{-2}$ 1·3<br>Ba, Y | 0·2 10<br>Ba, Y | 2·5 75<br>Ba, Y, I | 400 8000<br>N, Ba, Y, K |
| 5 min. | $8\cdot10^{-5}$<br>Ba, Sr | $3\cdot10^{-3}$ 0·2<br>Ba | $6\cdot10^{-2}$ 3<br>Ba, Na, Mn | 0·7 20<br>Ba, I, Na, Sn | 200 4000<br>N, Ba, K, Cl |
| 1 hr. | $3\cdot10^{-5}$<br>Sr, Ba | $10^{-3}$ $7\cdot10^{-2}$<br>Ba, Na | $3\cdot10^{-2}$ 1·5<br>Na, Mn, Ba | 0·35 10<br>I, Na, Sn, Pb, Na | 13 250<br>N, Cl, I |
| 6 hr. | $8\cdot10^{-6}$<br>Sr, Ba | $10^{-3}$ $7\cdot10^{-2}$<br>Ba, Na | $2\cdot10^{-2}$ 1<br>Na, Ba | 0·25 7<br>I, Na, Pb, Ba | 5 100<br>I, Ba, Na |
| 1 day | $10^{-6}$<br>Ba, Sn | $5\cdot10^{-4}$ $3\cdot10^{-2}$<br>Ba, Na | $10^{-2}$ 0·5<br>Na, Ba | 0·2 6<br>I, Na, Pb, Ba | 4 80<br>I, Ba, Na |
| 10 days | $3\cdot10^{-7}$<br>Sn | $10^{-5}$ $7\cdot10^{-4}$<br>Sn, Ba, P | $4\cdot10^{-4}$ $2\cdot10^{-2}$<br>Sn, P | 0·1 3<br>I | 2 40<br>I |

## Table 5

*Calculated radioactivity induced in food by radiation of different energies if the susceptible elements are assumed to be present in food in amounts which are to be expected in practice.*

(Note: The radioactivity is expressed as a proportion of the maximum permissible concentration in drinking water).

| Time | Cobalt-60 | 5 MeV Elect. | 5 MeV X-ray | 7 MeV Elect. | 7 MeV X-ray | 10 MeV Elect. | 10 MeV X-ray | 15 MeV Elect. | 15 MeV X-ray |
|---|---|---|---|---|---|---|---|---|---|
| Initial (canned meat) | $2\cdot10^{-8}$ | $2\cdot10^{-5}$ | $10^{-3}$ | $5\cdot10^{-4}$ | $2\cdot10^{-2}$ | $4\cdot10^{-3}$ | 0·1 | 50 | 1000 |
| | In, Sn | Na, Br | | Na | | Na, Br, Sn | | N, K, P | |
| (canned veg.) | $10^{-7}$ | $2\cdot10^{-5}$ | $10^{-3}$ | $6\cdot10^{-4}$ | $3\cdot10^{-2}$ | $4\cdot10^{-3}$ | 0·1 | 50 | 1000 |
| | Sr, Ba, In | Br, Y, Mn | | Mn, Na | | Br, Mn, Sn | | N, K, P | |
| 5 min. (canned meat) | $2\cdot10^{-8}$ | $10^{-5}$ | $7\cdot10^{-4}$ | $5\cdot10^{-4}$ | $2\cdot10^{-2}$ | $3\cdot10^{-3}$ | 0·1 | 40 | 800 |
| | In, Sn | Na | | Na | | Na, Sn | | N, K, P | |
| (canned veg.) | $7\cdot10^{-8}$ | $10^{-5}$ | $7\cdot10^{-4}$ | $6\cdot10^{-4}$ | $3\cdot10^{-2}$ | $3\cdot10^{-3}$ | 0·1 | 40 | 800 |
| | Sr, In | Mn, Na | | Mn, Na | | Mn, Sn, Na | | N, K, P | |
| 1 hr. (canned meat) | $2\cdot10^{-8}$ | $10^{-5}$ | $7\cdot10^{-4}$ | $5\cdot10^{-4}$ | $2\cdot10^{-2}$ | $3\cdot10^{-3}$ | 0·1 | 0·8 | 15 |
| | In, Sn | Na | | Na | | Na, Sn | | N, Cl, Na | |
| (canned veg.) | $7\cdot10^{-8}$ | $10^{-5}$ | $7\cdot10^{-4}$ | $5\cdot10^{-4}$ | $2\cdot10^{-2}$ | $3\cdot10^{-3}$ | 0·1 | 0·7 | 15 |
| | Sr, In | Mn, Na | | Mn, Na | | Mn, Sn, Na | | N, Cl | |
| 6 hr. (canned meat) | $10^{-8}$ | $5\cdot10^{-6}$ | $3\cdot10^{-4}$ | $5\cdot10^{-4}$ | $2\cdot10^{-2}$ | $10^{-3}$ | $3\cdot10^{-2}$ | $2\cdot10^{-2}$ | 0·3 |
| | In, Sn | Na | | Na | | Na, Sn | | | |
| (canned veg.) | $2\cdot10^{-8}$ | $3\cdot10^{-6}$ | $2\cdot10^{-4}$ | $3\cdot10^{-4}$ | $10^{-2}$ | $10^{-3}$ | $3\cdot10^{-2}$ | $10^{-2}$ | 0·2 |
| | Sr, In, Sn | Na, Mn | | Na, Mn | | Na, Mn, Sn | | Ca, Sn, Na | |
| 1 day (canned meat) | $5\cdot10^{-9}$ | $3\cdot10^{-6}$ | $2\cdot10^{-4}$ | $2\cdot10^{-4}$ | $10^{-2}$ | $6\cdot10^{-4}$ | $2\cdot10^{-2}$ | $7\cdot10^{-3}$ | 0·15 |
| | Sn | Na | | Na | | Na, Sn | | Na, Sn | |
| (uncanned meat) | $2\cdot10^{-10}$ | | | | | $5\cdot10^{-4}$ | $2\cdot10^{-2}$ | $5\cdot10^{-3}$ | 0·1 |
| | In | | | | | Na | | Na | |
| (canned veg.) | $5\cdot10^{-9}$ | $2\cdot10^{-6}$ | $10^{-4}$ | $10^{-4}$ | $5\cdot10^{-3}$ | $4\cdot10^{-4}$ | $10^{-2}$ | $10^{-2}$ | 0·2 |
| | Sn | Na, P | | Na, P | | Na, Sn | | Ca, Na, Sn | |
| (uncanned veg.) | $4\cdot10^{-10}$ | | | | | $3\cdot10^{-4}$ | $10^{-2}$ | $7\cdot10^{-3}$ | 0·15 |
| | In, Sr, Ba | | | | | Na, Pb, I | | Ca, Na | |
| 10 days (canned meat) | $5\cdot10^{-9}$ | $2\cdot10^{-7}$ | $10^{-5}$ | $10^{-5}$ | $5\cdot10^{-4}$ | $6\cdot10^{-5}$ | $2\cdot10^{-3}$ | $10^{-3}$ | $2\cdot10^{-2}$ |
| | Sn | Sn, P | | P, Sn | | Sn, P | | Sn, Na | |
| (uncanned meat) | $10^{-11}$ | $10^{-7}$ | $5\cdot10^{-6}$ | $6\cdot10^{-6}$ | $3\cdot10^{-4}$ | $3\cdot10^{-5}$ | $10^{-3}$ | $4\cdot10^{-4}$ | $8\cdot10^{-3}$ |
| | Sn | P | | P | | P, I | | Na, I | |
| (canned veg.) | $5\cdot10^{-9}$ | $3\cdot10^{-7}$ | $2\cdot10^{-5}$ | $2\cdot10^{-5}$ | $10^{-3}$ | $10^{-4}$ | $3\cdot10^{-3}$ | $2\cdot10^{-3}$ | $3\cdot10^{-2}$ |
| | Sn | P, Sn | | P, Sn | | P, Sn, I | | Ca, Sn, I | |
| (uncanned veg.) | $3\cdot10^{-11}$ | $2\cdot10^{-7}$ | $10^{-5}$ | $10^{-5}$ | $5\cdot10^{-4}$ | $6\cdot10^{-5}$ | $2\cdot10^{-3}$ | $10^{-3}$ | $2\cdot10^{-2}$ |
| | Cd, Sn | P | | P | | P, I | | Ca, I, Na | |

# APPENDIX III

## *THE EFFECTS OF IRRADIATION ON THE NUTRITIVE VALUE OF FOODS*

*Prepared for the Working Party by the Ministry of Agriculture, Fisheries and Food*

1. Initially, irradiation was studied with a view to the sterilisation of food. As a result much of the work on destruction of nutrients relates to doses of 5–6 Mrad. The type of radiation is not specified in all the early reports.

## EFFECTS ON MACRONUTRIENTS

2. Although sterilising and sub-sterilising doses of irradiation produce changes in food constituents sufficient in many instances to affect the odours and flavours of foods the chemical changes are, in fact, exceedingly small. The changes in the macronutrients are insufficient for any reduction in the calorie value of a food to be observed and no appreciable effects on digestibility have been demonstrated: Table 6.

TABLE 6

*Percentage availability of the macronutrients in diets composed of nine frozen-stored irradiated and non-irradiated foods* [251].

| *Nutrient* | *Control* | *Irradiated (5·58 Mrad)* |
|---|---|---|
| Protein | 85·9 | 87·2 |
| Fat | 93·3 | 94·1 |
| Carbohydrate | 87·7 | 87·9 |

### Proteins

3. Although the effects of irradiation on protein are small [42, 279], some denaturation has been observed, (e.g., in the thick white of whole egg) [29]. Some of these changes involve molecular rearrangement and polymerisation producing decreases in the anti-genicity of ovalbumin and milk proteins [163, 251]. The thermal stability and solubility of the fibrous protein collagen are more markedly affected as a result of destruction of the hydrogen bonded structure [8, 9]. Changes in meat pigments have been observed [73]. However, doses of gamma-radiation up to 0·5 Mrad have no effect on the protein of wheat [59] and the normal breakdown of protein which occurs in cheese ripening is unaffected by gamma-radiation under 1 Mrad [4].

4. Changes have also been observed in milk protein resulting in some loss of biological value [147, 159, 204, 240], possibly due to loss of cystine. These changes produced by gamma-radiation involve increases in the sulphydryl content [163, 184]; in certain circumstances decreases have been observed [276].

5. Recent work [139] has shown that in meat treated with a sterilising dose (5 Mrad) there was only a slight amount of amino acid loss (less than 10 per cent) spread evenly over the nineteen acids estimated except for phenylalanine which suffered an 18 per cent loss, whilst in one study undertaken for the U.S. Armed Forces Quartermaster several kinds of meat, fish and vegetable showed

no detectable loss of any amino acid either immediately after irradiation at 2·79 and 5·58 Mrad or after 6 months storage at room temperature [43]. The individual amino acid components of proteins are more susceptible in isolation [15, 251].

6. Irradiation appears to affect the digestibility of proteins in a manner comparable with heat treatments [159, 204, 205]: Table 7.

TABLE 7

*Effect of heat and irradiation on the true digestibility of proteins.*

| *Protein* | *Raw* | *Heat processed* | *Irradiated (2·79 Mrad)* |
|---|---|---|---|
| Pea | 92·2 | 91·4 | 90·8 |
| Lima Bean | 68·1 | 76·6 | 70·0 |
| Wheat gluten | 98·7 | 98·5 | 99·1 |
| Corn | 91·1 | 92·4 | 92·9 |
| Milk/liquid condensed | 97·9 | 96·7 | 96·9 |
| Beef | 100 | — | 100 |

7. Digestibility is increased by both treatments for lima beans and corn. There are slight decreases with both treatments for peas and milk. Heat destruction of trypsin inhibitor has been suggested as the reason for the appreciably greater increase in digestibility in lima bean protein on heat processing compared with irradiation. No explanation has been offered for the slight decreases in digestibility with both treatments in pea protein while with milk the slight decrease on irradiation has been ascribed to radiation destruction of cystine [104, 147].

**Fats**

8. Irradiation of lipids or lipid containing foods results in small changes related to the size of the dose applied, in which peroxides, [4, 159, 216] polymers and carbonyl compounds [205, 104] are produced. The production of peroxides which occurs to a greater extent in animal than in vegetable fats for similar treatments [199, 218] may cause oxidative rancidity to develop [108, 292].

9. The destruction of separated lipids is greater for the same irradiation dose than for the same lipid when a constituent of a food. This protective action has been ascribed to the presence in the foods of such antioxidants as cysteine and vitamin A [251].

10. The effect of environment is particularly evident when fatty foods are irradiated. In the absence of oxygen the production of peroxides is completely prevented [183, 218]: Table 8.

TABLE 8

*Lipid peroxide values for irradiated beef and pork.*

| Radiation dose (Mrad) | In air | | In nitrogen | |
|---|---|---|---|---|
| | Beef | Pork | Beef | Pork |
| 0·3 | 26 | 50 | 0 | 0 |
| 1·0 | 34 | 41 | 0 | 0 |
| 3·0 | 42 | 91 | 0 | 0 |
| 10·0 | 49 | 95 | 0 | 0 |

11. Irradiation of fats appears to decrease the rate at which they are digested and absorbed; this has been ascribed to the presence of irradiation induced carbonyls or to a reduction of lipase activity caused by irradiation. The net nutritive value to the consumer, however, is not altered [216, 221, 214].

12. Fats treated with doses of irradiation up to 6 Mrad do not according to the evidence available develop any dangerous properties; however, it is known that polyunsaturated fatty acids undergo autoxidation when irradiated (presumably due to the production of peroxides) and that the products of autoxidation can give rise to toxic effects. In a recent investigation [165] an increased mortality was observed in rats at 40 weeks when they were fed on a diet containing 20 per cent by weight of soyabean oil irradiated with 9·3 Mrad. When the oil was irradiated with the very large dose of 93 Mrad the diet decreased the growth and protein utilisation efficiency of the rats in 10 weeks and within 6 months 18 per cent of them had died. No definite causes for the increased mortality could be ascertained from macroscopic and microscopic examination of the rats that died though at the 93 Mrad dose some changes were observed in certain organs.

13. The possibility that carbonyls in the diet might produce undesirable effects has recently been tested [214]. Rats were forced fed corn oil to which had been added 50–100 times as much carbonyl compounds as might be encountered in a diet containing irradiated meats. No gross effects of this diet were observed in 20–30 days and it appears that the rat metabolises ingested carbonyl compounds adequately and rapidly enough to prevent any significant accumulation or toxic effect though the passage of lipids containing carbonyls through the gastro-intestinal tract is delayed. This delaying effect is apparently due to the modifying of the surface properties of emulsions rather than a direct effect on lipases.

**Carbohydrates**

14. Ionising radiations produce oxidative changes and depolymerisation in carbohydrates. These changes are slight and cause little or no loss of nutritional value [59, 155, 159, 253].

15. The treatment of potatoes with gamma-radiation from a cobalt-60 source at a dose of 0·003 Mrad is reported as leading to an increase in the concentration of free sugars [39, 280].

16. The constituents of the cell walls of plant tissues (pectin and cellulose compounds) become softened when irradiated [154] which can result in practical difficulties in the application of the process to fruits and vegetables.

17. The digestibility of carbohydrates following irradiation does not appear to be appreciably affected. The few references available in the literature are conflicting as to whether any effects can or cannot be demonstrated [216, 251, 254].

**Effect on energy value**

18. Feeding experiments with rats in which irradiated foods (2·79 or 5·58 Mrad) formed 35 per cent (dry solids) of their diet showed that the inclusion of such a high proportion of irradiated foods did not affect the caloric efficiency of the animals [159, 251, 254, 268]: Table 9.

TABLE 9

*Metabolisable energy value of macronutrients following radiation treatment* [251]

| *Nutrient* | *Calories per gm.* | |
|---|---|---|
| | *Non-irradiated* | *Irradiated (2·79 Mrad)* |
| Casein | 4·56 ± 0·30 | 4·51 ± 0·22 |
| Lard | 8·82 ± 0·31 | 8·87 ± 0·39 |
| Carbohydrate * | 3·87 ± 0·20 | 3·78 ± 0·30 |

* Mixture of sucrose, starch and dextrin

## EFFECTS ON VITAMINS

19. When foods are exposed to ionising radiations losses of some vitamins may occur, the extent of the loss depending on the vitamin, the food, the dose and the environment (e.g., irradiated in air or nitrogen, food frozen or not). Nutrients irradiated in isolation are usually more susceptible to destruction than when irradiated in complex systems or in the foods of which they are normal constituents [246, 243, 251, 253]. Goldblith (1955) [108] in a review of some of the effects of radiation on nutrients reported that when vitamins or amino acids are exposed in pure solution some destruction is observed dependent on the sensitivity of the compound itself, the amount of energy to which it is exposed and the nature and physical state of the medium in which it is present. Nutrients are affected indirectly by reaction with the free radicals produced by radiation on their solvents. This effect is influenced by dilution, temperature and the protection of the nutrient by the presence of other constituents of the foods of which it normally is a component. The irradiation of vitamin C and riboflavin in pure solutions and in evaporated milk provides a good illustration of the last of these. In milk the amount of irradiation required to deactivate 63 per cent of the vitamin C is approximately ten times that required to deactivate the same proportion in pure solution and the corresponding ratio for riboflavin is approximately one hundred [108].

**Effects of environment**

20. The presence or absence of oxygen during irradiation of a food and whether the food is frozen or not affects the extent of its influence on vitamins and to some extent other nutrients, e.g., fats. Thus at 2·79 Mrad 40 per cent of vitamin

E in beef was destroyed with oxygen present but there was no destruction in nitrogen up to 31·8 Mrad [183, 188]. Protection is also given by freezing: in meat the destruction of thiamine [343] and glutathione [55] by radiation is reduced, the extent of reduction depending on the temperature: at —75°C there is almost no loss of thiamine compared with 24 per cent loss at —10°C and 60–70 per cent at between 0 and 40°C [343]; the freezing of water is probably responsible for a large part of the protection observed [55]. Vitamin C in frozen orange juice is almost completely protected, at doses up to 0·93 Mrad [249].

**Comparison with heat treatment**

21. The percentage loss of vitamins in foods sterilised by irradiation is of the same order of magnitude as, but in general rather greater than, that resulting from commercial sterilising heat treatments [178] or from ordinary cooking [251, 253]. Data from various sources (not cited) on the effects of cooking and irradiation were collected by Read [253] and are shown in Table 10. The losses from cooking shown in the table almost certainly include losses by leaching, and in meat drip.

TABLE 10

*Relative effects of heat and radiation on vitamin destruction in foods* [253].

| *Vitamin* | *Per cent destruction* | |
|---|---|---|
| | *Heat* | *Irradiation (2·79 Mrad)* |
| Thiamine | 60–70 | 55–65 |
| Riboflavin | 18–22 | 6–10 |
| Pyridoxine | 28–32 | 24–25 |
| Nicotine acid | 30–35 | 0–14 |
| Choline | ? | 0 |
| Folic acid | 35 | 0 |
| Inositol | ? | 0–5 |
| Vitamin A | 20 | 31–70* |
| Vitamin E | ? | 61* |

(* Dosage 0·44 Mrads in dairy products)

22. Losses of nutrients during heat processing vary with the severity of the treatment. With cereals 15 per cent thiamine is lost in the baking of bread [58] and 28 per cent in the baking of biscuits [57]. With whole milk losses vary from less than 10 per cent thiamine and no pyridoxine in H.T.S.T. (high temperature short time) pasteurisation to 40 per cent thiamine and 60 per cent pyridoxine in the preparation of evaporated milk [157]. During the canning of meat losses can range from 24–62 per cent thiamine, 5–33 per cent riboflavin and 3–29 per cent nicotinic acid [113] while the curing of ham and bacon give losses of 20–27 per cent, 3–8 per cent and 0·30 per cent thiamine, riboflavin and nicotinic acid respectively [291, 112].

23. The loss of vitamin C during irradiation varied between foods but in general parallel losses occurred in heat processing [253].

24. The susceptibility of individual vitamins to the irradiation of the foods containing them varies widely but so does their susceptibility to cooking treatments and the effects of the two treatments appear to be approximately similar quantitatively. It is clearly important since food is likely to be largely irradiated in the raw state to know whether the effects of irradiation and cooking are additive. There is, however, little available evidence on this point. In one investigation [342] in which calves' livers were irradiated at both 3 and 6 Mrad subsequent cooking did not cause further loss of thiamine; on the other hand in another investigation [345] using a composite diet containing fifteen irradiated foods, cooking further accentuated the thiamine destruction produced by radiation. Animal feeding studies [346] showed that there were small differences between the nutritive values of foods when the foods were cooked and when they were both cooked and irradiated. Fifteen foods were included in the composite ration used for these tests, and the diets were probably fairly rich in all nutrients.

25. The effects of irradiation with 4·8 Mrad followed by cooking have been reported in work done for the U.S. Armed Forces Quartermaster [314]. In general there is a further loss of vitamins resulting from cooking (in ways appropriate to various products) following irradiation. In the case of thiamine the sum of irradiation plus cooking resulted in almost total loss of the vitamin. For riboflavin the effect was less marked, but the sum of effects was in general greater than if the product was simply canned or dehydrated and cooked.

### Effects on individual vitamins

*B. Complex*

26. Within this group of vitamins nicotinic acid is stated to be the most resistant to ionising radiations, followed by riboflavin with thiamine the most sensitive [244, 251, 342].

TABLE 11

*Vitamin destruction in beef exposed to 2·79 Mrad* [154]

| *Vitamin* | *Per cent destruction* |
|---|---|
| Vitamin $B_1$ | 60–67 |
| Pyridoxine | 20–25 |
| Riboflavin | 8–10 |
| Nicotinic acid | 0 |
| Choline | 0 |
| Folic acid | 0 |

This is shown in Table 11 while data on thiamine destruction in five different thiamine-containing foods irradiated in nitrogen are shown in Table 12. The data in Table 11 are from a different source from those in Table 10 and the losses of thiamine, pyridoxine and nicotinic acid for a dose of 2·79 Mrad are not the same.

TABLE 12

*Destruction of thiamine in meats irradiated in nitrogen (1·86 Mrad)* [118]

| Meat | Per cent destruction |
|---|---|
| Lamb | 25 |
| Veal | 22 |
| Bacon | 35 |
| Lake trout | 9 |
| Turkey | 14 |

27. Wilson (1959) [343] reported a 75 per cent destruction of thiamine in beef or pork irradiated with 2 Mrad. He also found that the extent of this destruction was not altered by using oxygen-free packing techniques. Other workers [308] have, however, reported greater destruction of thiamine in the presence of oxygen than in a nitrogen atmosphere.

28. Wilson [343] made a significant advance in technique by demonstrating that there was no thiamine destruction in meat when irradiated at —75°C.

29. Not only do different vitamins vary in their sensitivity to radiation but individual vitamins vary markedly from food to food as shown in Table 13.

TABLE 13

*Vitamin destruction in foods* exposed to two dose levels of gamma-irradiation* [352]. *(from mixed fission products in spent fuel rods)*

| | Per cent destruction | | | | | |
|---|---|---|---|---|---|---|
| | Thiamine | | Riboflavin | | Nicotinic acid | |
| Dose (Mrad) | 2·79 | 5·58 | 2·79 | 5·58 | 2·79 | 5·58 |
| Bacon | — | 93 | — | 7 | — | 0 |
| Beef | 76 | 85 | 5 | 4 | 2 | 1 |
| Haddock | 68 | 76 | 0 | 4 | 14 | 9 |
| Ham (fresh) | 87 | 96 | 0 | 0 | 2 | 2 |
| Turkey | 76 | 77 | 27 | 50 | 7 | 0 |
| Beets | 52 | 75 | 14 | 10 | 0 | 10 |
| Milk (powdered) | 0 | 0 | 0 | 0 | 35 | 20 |
| Peaches | 94 | 98 | 0 | 0 | 48 | 56 |

(* The foods were frozen and packed in solid carbon dioxide for shipment to the radiation source, they thawed during irradiation and were again packed in solid carbon dioxide for shipment to the U.S. Army Medical Nutrition Laboratory, Denver).

30. Thiamine is again seen to be the most sensitive B vitamin to irradiation except in dry products such as powdered milk. Riboflavin appears relatively stable. Nicotinic acid was relatively stable except in peaches, which are not an important source of the vitamin, but here the extensive degradation may have been due to the inclusion of Vitamin C in the commercial frozen packs irradiated.

31. 0·1 Mrad [4] produced in pasteurised liquid milk a loss of 40 per cent of thiamine and 7 per cent of riboflavin; no other information is available to us on the effects of small doses of radiation on liquid milk.

32. Some recent British work done at the Atomic Energy Research Establishment [153] has been devoted to examining the effects on some B vitamins of wheat and frozen whole eggs when gamma-radiation (cobalt-60) treatments effective in disinfecting wheat and eliminating salmonellae in frozen egg were used. Doses ten times those necessary for effective treatments were also examined: Table 14.

TABLE 14

*Destruction of some B complex vitamins by gamma-radiation in stored Manitoba wheat and in frozen whole egg. (data from A.E.R.E., Wantage)* [153].

| Food | *Per cent destruction* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Thiamine* | | *Riboflavin* | | *Nicotinic acid* | | *Pantothenic acid* | | *Biotin* | | *Pyridoxine* | |
| Dose (Mrad) | 0·02 | 0·2 | 0·02 | 0·2 | 0·02 | 0·2 | 0·02 | 0·2 | 0·02 | 0·2 | 0·02 | 0·2 |
| Manitoba Wheat | 0 | 0 | 2·8 | 0 | 0 | 15·4* | 4·2* | 10·6* | 1·1 | 10·1* | 2·4 | 2·9 |
| Dose (Mrad) | 0·5 | 5·0 | 0·5 | 5·0 | 0·5 | 5·0 | 0·5 | 5·0 | 0·5 | 5·0 | 0·5 | 5·0 |
| Frozen Whole Egg | 27·6* | 59·2* | 0 | 0 | 7·5 | 18·1* | 0 | 0 | 0 | 0 | — | — |

* Significant at P = 0·05, i.e. values of these magnitudes could occur by chance only once in twenty observations with the experimental variations observed.
(With heat pasteurisation at 66°C for 2½ minutes the only significant loss in the whole egg was 6·1 per cent of thiamine).

33. There is some loss of pantothenic acid in wheat at both the effective and the high dose treatments and small losses of nicotinic acid and biotin at the high level only. In frozen egg nearly 30 per cent of the thiamine is lost in the 0·5 Mrad treatment and this loss is doubled with a dose of 5·0 Mrad. At the higher dose there is also a loss of nicotine acid (18·1 per cent).

34. Little work has been done on the effects of irradiation on pyridoxine, choline or folic acid but Markakis *et al* [194] report that vitamins $B_{12}$ is more sensitive to irradiation than vitamin C.

**Vitamin C**

35. Vitamin C is very sensitive to irradiation but losses may be relatively low at low doses, e.g., for sprout inhibiting doses on potatoes (0·01 – 0·02 Mrad/ gamma-radiation, cobalt-60) the loss may be 20 per cent [39, 280] but some Russian workers [86] have reported actual increases in vitamin C in potatoes irradiated in the 0·05 – 0·1 Mrad range (gamma-radiation), while Canadian workers [230] have reported no appreciable loss at 0·01 Mrad (gamma-radiation).

36. The destruction of vitamin C in orange juice by high voltage cathode rays (3 MeV) increases with increasing dosage, from 4 per cent destruction at a dose of 0·093 Mrad, through 22 per cent and 26 per cent at doses of 0·279 and 0·372 Mrad respectively to 59 per cent at a dose of 0·93 Mrad [249].

37. In strawberries, gamma-radiation at doses of 0·3 and 0·4 Mrad produce respectively 63 per cent and 81 per cent destruction of vitamin C [47] though the storage life of strawberries is reported as being extended considerably, without loss of vitamin C, at a dose of 0·5 Mrad from an electron accelerator (1 MeV electrons) [350]. This difference may be due to differences in penetrative power of the two types of radiation.

38. Doses of up to 0·6 Mrad are reported as causing no loss of vitamin C in blackcurrant juice [144].

39. The loss of vitamin C in vegetables varies with the vegetable: Table 15.

TABLE 15

*Vitamin C destruction in certain vegetables by irradiation with high voltage cathode rays* [224].

Dose 1.86 Mrad

| *Food* | *Per cent destruction* |
|---|---|
| Asparagus | 71·5 |
| Broccoli | 86·5 |
| Green beans | 92·1 |
| Spinach | 64·5 |

40. Even low doses with gamma-radiation cause losses of vitamin C in milk [4].

**The fat soluble vitamins**

41. The fat soluble vitamins A, E and K are generally more sensitive to ionising radiation than most of the water soluble vitamins. These vitamins can be destroyed by reaction with autoxidised fatty acids *in vitro* and *in vivo*. The autoxidation of unsaturated fatty acids is accelerated by irradiation in air or oxygen and is initiated even when irradiation is carried out in a vacuum or in an atmosphere of inert gas [253, 263].

**Vitamin A**

42. Vitamin A is very sensitive to irradiation [109], even more so than to heat [251]. Irradiation of whole milk with gamma rays at 0·44 Mrad results in the destruction of 40 per cent of the carotenoids and 70 per cent of the vitamin A content [109, 164, 290].

43. The stability of carotenoids depends on whether or not they are dissolved in fats. If the pigments are so dissolved they are more liable to oxidation than if not. In tomatoes where the pigment is not in fat it is more resistant. The effects of various environments on the stability of carotenoids are shown in Table 16.

TABLE 16

*Stability of carotenoids in irradiated foods* [218].

| *Food* | *Carotenoid environment* | *Per cent undestroyed by 4 Mrad (cobalt-60)* |
|---|---|---|
| Salmon | highly unsaturated fat | 2 |
| Chicken | unsaturated lipid | 17 |
| Beef | unsaturated lipid | 24 |
| Shrimp | bound to protein | 69 |

**Vitamin D**

44. There is little information available on the radiation sensitivity of vitamin D.

**Vitamin E**

45. Vitamin E is very sensitive to irradiation even in meat which contains very little of the vitamin [164, 238, 251]. Irradiation of whole milk with a dose of 0·44 Mrad from a cobalt-60 source caused 61 per cent destruction; in cultured and sweet cream butter a slight loss is observed with 0·005 Mrad and a loss of 82 per cent at 0·1 Mrad [4].

**Vitamin K**

46. The synthetic vitamin $K_3$ (menadione or menapthone) is more susceptible than $K_1$ or $K_5$ [273] Rats fed beef irradiated at both 2·79 Mrad and 5·58 Mrad as 35 per cent of their diet developed vitamin K deficiency symptoms [206, 251]. This was found, however, to be due to their normal coprophagy being inhibited and therefore their not receiving a supplement of vitamin K synthesised by bacteria in the gut. When given a vitamin K supplement or fed a mixed irradiated diet containing vegetables in which the destruction of Vitamin K is small the rats did not develop haemorrhagic symptoms. The loss of vitamin K activity has been found to be comparatively small when a natural food is irradiated [273].

## SUMMARY

47. Although the treatment of foods with ionising radiations may produce alien odours and flavours the destruction of the nutrients in the foods approximates to that of cooking the same foods. Individual vitamins or macronutrients irradiated in isolation show much larger changes than those irradiated as constituents of foods due to the mutually protective action of nutrients on each other. The generalisation may be made that if a mixed diet is eaten then a large proportion may consist of irradiated foods without any nutrient deficiency being evident.

48. The macronutrients; proteins, fats and carbohydrates are not significantly altered by irradiation in terms of nutrient values and digestibility.

49. Amongst the water soluble vitamins thiamine, pyridoxine and ascorbic acid are the most susceptible to irradiation.

50. American short-term feeding trials with human volunteers have shown no evidence of nutritional imbalances or of the presence of toxic substances resulting from irradiation of the foods used [236].

51. Most of the American research work on the effects of ionising radiations on the composition of nutrients and on the nutritive values of irradiated foods has been done using high dose treatments. This involves the assumption that the changes produced are qualitatively similar at all doses which is not necessarily valid. There is need for work to be done using a wider range of doses with particular references to the fat soluble vitamins.*

# APPENDIX IV

## *RELEVANT ASPECTS OF MICROBIOLOGY*

### A. The development of "pasteurisation" and the use of the term in this Report

1. The classical investigations of Louis Pasteur showed that the souring of wine and beer could be prevented by heating them to a temperature of 50–60°C for a few minutes after they had been bottled. Pasteur thus greatly helped the wine and beer industries of France and it was natural that the practical application of this discovery was dubbed "pasteurisation". Shortly after Pasteur's investigation of wine and beer the souring of milk was found to be delayed by a similar application of heat and, as a result, dairies, particularly those in the larger towns of Europe and America, adopted this process of "pasteurisation" with the object of prolonging the time during which milk could be stored without becoming sour. The development of methods of closely controlling the time and temperature of treatment, and investigation of their influence, revealed the fact that a defined combination of time and temperature permitted the destruction in milk not only of the micro-organisms responsible for souring but also of certain pathogenic organisms which might be present, of which the most important was *Mycobacterium tuberculosis*. This aspect of the pasteurisation of milk was recognised to be of great significance by public health authorities, and gradually the importance of pasteurisation in controlling such pathogens has outweighed the original commercial object of the process, namely the prolongation of the time for which milk could be stored without going sour. Pasteurisation is the term which is now widely applied to processes which are designed to reduce the number of pathogenic organisms in food to a safe limit, and its use in this sense has been adopted with respect to suitable heat treatment of ice cream and, more recently, of bulked liquid whole egg, foods in which the prevention of souring is not the prime object of the treatment. A process of pasteurisation has also been applied to ham, but in such an instance the nature of the food makes difficult the even application of the amount of heat needed to ensure the necessary microbiological control.

2. With respect to the treatment of food by irradiation the term pasteurisation has been applied both to a reduction in the number of spoilage organisms in food to such a degree that the useful storage time is prolonged and to a reduction

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* Unpublished material from the Technical Meeting on the Control of Wholesomeness of Irradiated Foods (F.A.O., W.H.O., I.A.E.A., Brussels, October, 1961).

in the number of pathogenic organisms which may be present in particular foods. The Working Party decided to use the word pasteurisation in both these senses and to employ it to describe: (a) the application of radiation to control the number of micro-organisms with the object of prolonging useful storage life either in a refrigerator or at room temperature. Examples of this use of the term are the reduction of the numbers of organisms on meat and fish and of moulds on fruit such as strawberries; for these purposes the doses of radiation are 0·3 to 1·0 Mrad respectively; (b) the use of radiation to reduce the number of micro-organisms of specific pathogenic strains. An example of the use of irradiation for pasteurisation with respect to pathogens is the treatment of frozen whole egg to reduce the number of *Salmonellae*. Irradiation with 0·5 Mrad provides an inactivation factor of $10^7$ for the most radiation-resistant strain of *Salmonellae* so far encountered.

**B. Clostridium botulinum and botulism**

3. Botulism does not arise from infection by *Cl. botulinum* of a person suffering from this condition. It is an intoxication resulting from ingestion of *Cl. botulinum* toxin which is liberated during growth by certain strains of the spore-forming microbe, *Clostridium botulinum*. It carries a high mortality. The word "botulism" is derived from the Latin "botulus", a sausage, and the condition of "sausage poisoning", prevalent in Germany during the eighteenth century, was almost certainly botulism. The causative organism was isolated and identified in Belgium by Van Ermengem in 1896, and was named by him *Bacillus botulinus*. Later the same organism was isolated from a number of different foods which had been suspected of causing botulism. In nearly all early instances food containing meat was involved, but one exception was provided by an outbreak at Darmstadt, Germany, in 1904, which was traced to the consumption of preserved beans, the first occasion on which a foodstuff of vegetable origin had been implicated. Vegetables have frequently been incriminated in subsequent investigations. It is noteworthy that the strain of *B. botulinus* isolated from the beans was found to differ from that originally isolated by Van Ermengem.

4. These findings stimulated much research and now three main types of *Clostridium botulinum*, as the organism was renamed, came to be associated with botulism in the human being — *Cl. botulinum* Type A, *Cl. botulinum* Type B and *Cl. Botulinum* Type E. A new Type F has recently been recognised. Outbreaks of botulism caused by Type A are commoner in this country than those caused by Type B, and both are associated with food that has been smoked, pickled or canned and then consumed without cooking or after inadequate cooking. Type E is particularly associated with fish and marine mammals. Most of the instances of botulism which were ascribed to the presence in the food of Type E have been caused by smoked or inadequately cooked fish in North America and Japan. There have been isolated outbreaks of botulism from Type C, sub-strains alpha and beta, and from Type F.

5. In Great Britain the first known outbreak of botulism was reported at Loch Maree, Scotland, in 1922 when eight people died from eating sandwiches made with wild-duck paste. From the remains of the paste *Cl. botulinum* Type A was isolated. Since that time four other incidents, all in London, have been reported. Three occurred in August, 1935, two being associated with nut meat brawn, a vegetarian food, and in these two outbreaks five people died. The third incident involved an elderly man who died three days after consuming a

home-made steak pie made a few days previously. *Cl. botulinum* Type B was isolated from the remains of the pie, the first occasion on which this strain was a known cause of botulism in Great Britain. In 1955 two Mauritian students in London developed symptoms of botulism twelve hours after eating canned pickled fish and vegetables prepared in Mauritius and brought to Great Britain by a friend. Both patients recovered.

6. Botulism has occured as a result of eating food which had been cooked and then kept for some time before consumption. The elderly man who died as the result of eating steak pie described it as tasting sour, although its sourness was not sufficient to prevent its consumption. In other instances the development of a cheese-like odour has been associated with the growth of *Cl. botulinum* but such an odour might easily escape detection in a strongly-flavoured food.

7. It would be expected *a priori* that the growth of *Cl. botulinum* in food, which is a necessary prerequisite for the production of toxin, would induce changes in the chemical composition of the food brought about by the metabolic activities of the growing micro-organism, and that these changes in composition would necessarily result in alterations in taste and odour. On the other hand there is evidence [70, 63] that in certain foods *Cl. botulinum* can multiply and produce toxin without giving adequate warning of its presence. In the cases described in paragraphs 4 and 5 above any change in taste of the contaminated food was insufficient to prevent consumption of it. It may therefore be concluded that it would be unsafe to assume that an effective natural warning exists of the presence of *Cl. botulinum* toxin in food in the form of a change in odour and taste of the food.

8. The properties of *Cl. botulinum*, and of its toxin, which are particularly relevant to the matters discussed in this Report, can now briefly be summarised. The organism is usually regarded as strictly anaerobic, although the term anaerobic is necessarily a relative one and the tension of oxygen needed to inhibit the growth of the organism in different foods is unlikely to be constant. The spores of *Cl. botulinum* are relatively resistant to destruction by heat, though not more so than are the spores of other micro-organisms sometimes responsible for the spoilage of food, such as *Cl. sporogenes* (see paragraph 99 of the main report). The spores of *Cl. botulinum* (see Table 3 of the main report) are the most resistant to the lethal effects of radiation of any pathogen known. The spores do not themselves produce the toxin, which is liberated during growth in the vegetative phase of the organisms' existence, after the spores themselves have been induced to germinate under suitable environmental conditions. The rate of toxin production is greatest when growth occurs at 35–37°C but it has been reported that after germination *Cl. botulinum* Type E grows and produces toxin at a temperature as low as 3·3°C [284]. A salt (sodium chloride) concentration of 8 per cent or more prevents germination of the spores without killing them so that if the salt is removed storage could be dangerous. In foods with 8 per cent or more of salt the susceptibility of the spores to destruction by heat is greatly increased. *Cl. botulinum* will not germinate or grow in foods with a pH of 4·0 to 4·5 or less but the spores remain viable and storage after reduction of the acidity of pickled foods could be dangerous under some conditions. With foods of a pH below 6 the lower the pH the greater the susceptibility of the spores to destruction by heat. Spores of *Cl. botulinum* are widely distributed in nature and are particularly widespread in soil. Foods which are liable to be contaminated with soil, such as vegetables and fruit, are therefore potential carriers of *Cl. botulinum* spores.

9. The question may reasonably be asked why is botulism not more common than it is? The answer is that a number of conditions must operate in sequence before the toxin can be produced in food in an amount sufficient to cause poisoning. Fresh food, cooked or uncooked, is usually safe because if it is contaminated at all with the organism this will be in spore form. For toxin to be produced the spores must germinate and the organism grow, and significant germination of the spores does not occur in the human being after consumption of the food which carries them. In general, the survival of spores, their germination and growth, and toxin production by the vegetative form of the organism occur only when the spores contaminate a non-acid, non-salted food, the heating of the food is inadequate to kill all the spores, the temperature and oxygen tension during subsequent storage are favourable for the growth of vegetative anaerobic bacteria, and the food is later consumed without thorough cooking. Such a concatenation of conditions is fortunately rare, and when it does occur it is liable to involve the growth of other bacteria whose activities render the food so unpalatable that it is rejected.

10. Botulism is commoner in some parts of the world than in others. In the United States of America an annual average of about 16 cases has been reported over the past ten years, although the cases reported during 1963 amount to about three times this number. In Great Britain a confirmed case of botulism has not been attributable to food prepared in the United Kingdom for more than 25 years. The possible reasons why botulism is more common in the United States than in Great Britain has therefore been considered. Undoubtedly an important factor is the greater popularity in the United States of home canned foods, particularly vegetables. A further possible reason may be that more non-sterile food is consumed which has been wrapped in plastic materials that may be impermeable to oxygen, and that "vacuum packing" is more common. A further important factor probably is a greater popularity, in the United States of raw or lightly cooked fish, such as smoked fish. Smoked white fish, prepared from fish caught in the Great Lakes, was responsible for three outbreaks of botulism in the United States in recent years. These were due to Type E of which an important characteristic is that it has been reported to grow and produce toxin at a temperature of 3·3°C. This strain of the organism has not so far been identified with certainty in Great Britain, although it has been responsible for a significant proportion of the recent outbreaks in the United States of America. But cosmopolitan culinary tastes spread widely in the world these days and smoked and lightly cooked foods, including fish, may well gain in popularity in Great Britain in the future.

11. The treatment of food by irradiation will doubtless tend to accelerate the use of air-tight packages for food. A tendency already exists in Great Britain towards the use for food of plastic cases and wrappings, and also towards the vacuum packing of foods. These considerations suggest that the freedom from botulism that Great Britain at present enjoys is not a birthright to be taken for granted but a fortunate possession that should be guarded with meticulous care. Since the uncontrolled use of irradiation for the treatment of food would very probably lead to an increase in the storage of non-sterile food in oxygen impermeable containers, the hazard that could arise in this respect clearly needs further close consideration.

12. The question next arises of whether the temperature attained during the cooking of food is necessarily sufficient to destroy any *Cl. botulinum* toxin already present. Different workers have tested different combinations of time and

temperature and some of the earlier results were confusing, even conflicting. However, more recent work shows that with a constant time of two minutes, heating at 60°C is sufficient to inactivate the toxin of Type A, at 70°C for Types B and E, and at 90°C for Types C and D. The toxin of Type F is stated in this report to be extremely heat labile. Type E toxin has been reported to require about 15 minutes at 60°C at pH 6·5 – 5·2 for destruction [228]. At the Working Party's suggestion Dr. M. Ingram of the Low Temperature Research Station (Agricultural Research Council), Cambridge, determined the actual temperature attained in the middle of a beef steak which had been cooked to an underdone condition popular for consumption in the United Kingdom. Under such conditions the steak became brown on the outside but remained raw in the middle. For a steak $\frac{1}{2}$ in. thick the maximum temperature attained in the middle during cooking was 60°C, and this was maintained for about three minutes. With a steak $\frac{3}{4}$ in. thick the maximum temperature was just below 40°C, and this was maintained also for 3 minutes. Obviously, whatever the temperatures and times may be that are necessary to destroy the various *Cl. botulinum* toxins, it would be unwise to assume that all forms of cooking are sufficient under all circumstances to inactivate all *Cl. botulinum* toxins.

13. The fact that *Cl. botulinum* is an anaerobic organism contributes to the rarity of botulism. The spores of the organism are widespread in soil, and evidence for its existence has been found in water both salt and fresh. Any contamination by the spores is likely to be on the surface of the food, where subsequent growth is presumably facilitated if the food is stored in the virtual absence of oxygen. The sausage was once particularly associated with botulism, and still is in some parts of the world, and the reasons for this almost certainly depend on the fact that a sausage skin may constitute an air-tight container into which is packed material which contains minced or finely chopped meat. If the surface flora of the meat included spores of *Cl. botulinum* the mincing or chopping would carry some of these into the middle of the mass, where anaerobic conditions would almost certainly obtain. Unless the sausages were then adequately cooked the consequences could obviously be serious.

14. In the canning industry it is helpful that the spores of *Cl. botulinum* are rather more susceptible to destruction by heat than those of the commonly occurring spoilage organisms. If therefore any fault occurs in heat processing whereby a significant proportion of the spores of *Cl. botulinum* escape destruction, the spores of the non-pathogenic organisms responsible for the spoilage of food will almost certainly survive in still larger numbers. The growth of these is then very likely to transform the food into an unpalatable product and, perhaps as a result of the metabolic formation of gas, may cause cans to blow. Such a warning of hazard is usually effective.

15. The irradiation of easily perishable food will nearly always be effected after it has been packed in containers which are almost certain to be air-tight and in which the food will subsequently be stored. The conditions of storage are therefore likely to approach that anaerobic state in which *Cl. botulinum* can flourish, given other satisfactory conditions. An attractive use of irradiation is likely to be for the prolongation of the storage life of meat. If any serious extension of the storage life of chilled meat is planned to follow preliminary pasteurisation by irradiation, the meat is likely to be enclosed in an airtight covering. This covering would stop the growth of moulds and would prevent adventitious contamination by micro-organisms during storage. The possibility cannot be ruled out that any surface contamination of the meat by *Cl. botulinum*

before treatment could constitute a hazard of botulism unless the storage temperature was below that at which Type E is able to grow, i.e. about 3°C, even though Type E has not been found on meat in Great Britain. Chilled meat is at present often stored at a temperature somewhat above this but since the present conditions of storage do not exclude oxygen from the surface of the meat, and Type E is at present unknown in Great Britain, the hazard of botulism is likely to be negligible and, in fact, is not realised in practice at present.

16. If irradiated but non-sterile food in an air-tight container were stored in a domestic larder at a temperature of 15°C or more the survival and germination of any spores of *Cl. botulinum* that were present might or might not be accompanied by the growth of spoilage organisms. If the latter were present and able to grow the food would probably be spoiled and rejected. If spoilage organisms were not present or not in sufficient numbers, the growth of *Cl. botulinum* and the production of its toxin might well fail to be associated with such spoilage of the food that it would be rejected. A grave hazard to health could then arise. With adequately cool storage, and above all with subsequent thorough cooking of the food, no hazard of microbiological origin should arise from the consumption of irradiated stored food even though it be not sterile. But as shown in the experiment described in paragraph 12 of this Appendix cooking cannot be relied upon to destroy *Cl. botulinum* toxin. It may be noted that 7 Mrad is needed to completely destroy the toxin of *Cl. botulinum* Type A when it is present in food [332].

**C. Clostridium welchii and food poisoning**

17. Food poisoning which results from the presence in food of *Clostridium welchii*, and which takes the form of an enteritis that can be mild but is usually severe, has become much commoner than before in the United Kingdom during the past twenty years or so. During the years 1957 to 1961 there have been 70 outbreaks in which *Cl. welchii* has been implicated, largely in schools and works where feeding in canteens occurs. In these outbreaks one-third or more of those at risk have been affected. In recent years similar outbreaks have been reported in the United States of America, Japan and in some European countries.

18. Six strains (A to F) are recognised of the anaerobic, spore-forming organism, *Cl. welchii.* This organism is widespread, its main habitat being the soil, although it is commonly found in the bowel of man and of animal. The strain responsible for food poisoning in the United Kingdom is commonly found in meat, and is relatively resistant to destruction by heat, and by radiation (see Table 3 of the main Report).

19. How enteritis results from the presence in food of *Cl. welchii* is still not certain, despite much relevant research. The production of a toxic substance probably occurs under suitable conditions in food contaminated by the organism, but the growth of the organism *in vitro* is not necessarily associated with the production of a recognisable filtrable toxin [227]. The toxin is not easily destroyed by heat and can survive ordinary cooking.

20. Because of its constant presence in the bowel of animals *Cl. welchii* is not infrequently present on the surface of carcase meat [306], and foods responsible for *Cl. welchii* food poisoning usually contain meat. The greater prevalence of such enteritis in the United Kingdom during the past twenty years probably originates in the changes in cooking habits which took place during the war of 1939–45, and which resulted from the strict rationing of meat and an increase

in communal catering. Under war conditions in Great Britain meat dishes were often cooked the day before consumption and then left at room temperature to cool. They were later warmed up immediately before consumption. The portions uneaten on the first occasion might be subjected to a repetition of the process. The habits which then developed appear to have resulted in lasting changes in the treatment of food in the United Kingdom. Unfortunately, the slow reheating of a cooked meat dish can provide good conditions for the germination and growth of any spores of contaminating *Cl. welchii* which may have escaped destruction in the process of cooking, and a relatively mild reheating is unlikely to destroy either the remaining organisms or any toxin which may have been formed. Heating to 39–49°C can favour the growth of *Cl. welchii* on meat though a temperature of 62°C or above can destroy the organism [306, 56].

21. With 5 Mrad of irradiation the inactivation factor for *Cl. welchii* in food is $10^{24}$ to $10^{21}$ (see Table 3). Irradiation of meat by, for example, 1 Mrad in order to effect pasteurisation might not necessarily reduce the number of any contaminating *Cl. welchii* organisms to a safe figure but if the pasteurised meat were stored at the cool temperature which might be expected in a refrigerator or larder, no hazard from the presence of *Cl. welchii* should arise. The Working Party has found no evidence about the effect of irradiation on the toxin.



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